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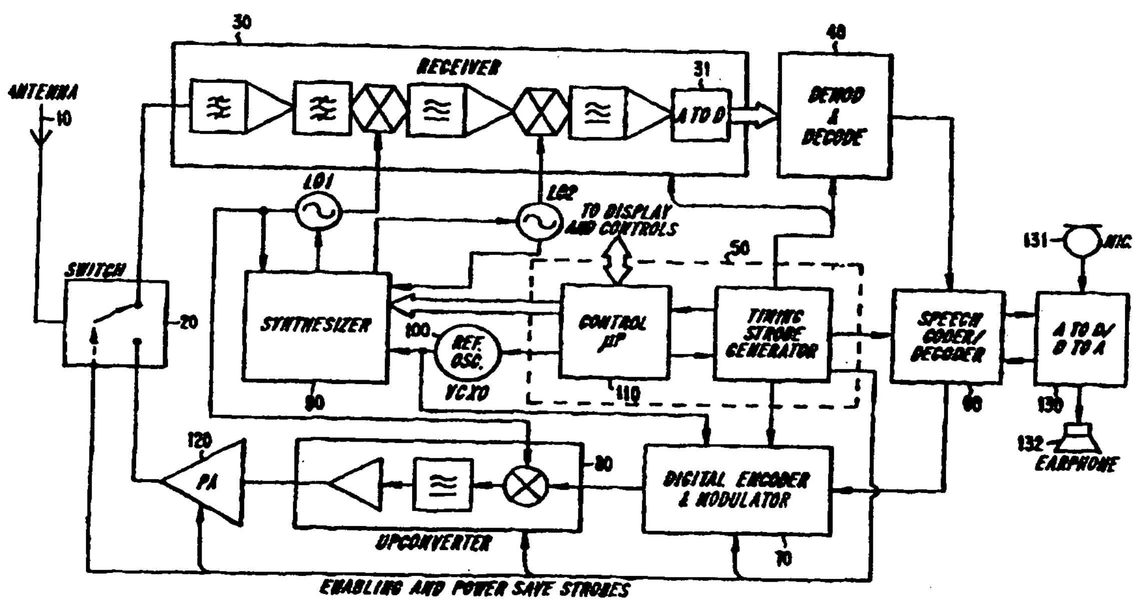



**(57) Abstract**

A method for supporting calls between two mobile stations within a satellite communication system is disclosed. First, when signals transmitted by a first mobile station using a narrowband transmission format are received at a satellite relay station, the received signals are sampled and digitized. The sampled and digitized signals are then stored in a buffer at a first rate. The stored data is then read out of the buffer at a faster rate than the first rate and modulated onto a downlink frequency to create a wideband transmission format. The modulated signals are then transmitted to the second mobile station.

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# TIME COMPRESSING TRANSPONDER

## Field of the Invention

The present invention relates to mobile radio communications systems employing orbiting satellites or relay stations and more particularly to a method and apparatus for supporting mobile-to-mobile calls relayed through a satellite relay station.

## Background of the Invention

The prior art contains several examples of duplex radio communications using Frequency Division Multiple Access (FDMA) in which different radio telephones each have a unique pair of frequencies for transmissions in the transmit and receive directions, for example, the U.S. AMPS cellular telephone system. The prior art also discloses duplex radio communication systems using Time Division Multiple Access (TDMA) in which each radio telephone has a unique time slot on a first shared frequency for communication in one direction, and a second unique time slot on a second shared frequency for communication in the other direction, for example, the European GSM digital system or the U.S. Digital Cellular standard IS-54. In these systems, the time slots in the respective directions are furthermore offset in time from each other so that the portable radiotelephones do not need to transmit and receive simultaneously. This eliminates the need for a transmit/receive duplexing filter which is required by a radiotelephone operating in a FDMA system. Instead, a so-called "time duplex" phone, as envisioned in the prior European Cellular System GSM, uses a simpler transmit/receive switch to couple the antenna alternately to the receiver or the transmitter.

In certain applications, neither TDMA nor FDMA provides an optimal solution. The TDMA system requires higher peak transmitter power to compensate for compressing the transmission into a time slot that is only a fraction of the total time, since it is the mean power that governs the range and quality of the communication. This is not an issue for a base station that in any case must have enough transmitter power to support all mobile stations, and the total power is the same for FDMA and TDMA solutions. It is simpler and cheaper for the TDMA base stations to have one high power transmitter and one antenna which can be timeshared between all base/mobile links using Time Division Multiplexing (TDM). However, it is often inconvenient for TDMA mobile stations to generate high peak power. On the other hand, it is inconvenient for FDMA mobiles to use antenna duplexing filters. Therefore, the present invention seeks to provide a method of using TDM on the base-to-mobile link (downlink) combined with FDMA on the mobile-to-base link (uplink), while avoiding the need for a duplexer.

The prior art discloses examples of mixed TDM/FDMA systems, such as the British Army's PTARMIGAN Single Channel Radio Access System (SCRA). The SCRA system is in fact a military radiotelephone system, and uses TDM on the downlink on a first frequency band while using FDMA on the uplink by allocating a separate frequency in a second frequency band to each mobile uplink. The SCRA system, however, requires either separate antennas for the uplink and downlink, respectively, or a duplexing filter to permit simultaneous transmission and reception through one antenna.

Figure 1 illustrate the prior art transmission format described in the U.S. Digital Cellular standard IS-54. A base station transmits information

continuously in frames of data which are 20ms long. The data in question is composed of digitized speech information generated by a digital speech compression algorithm interspersed with synchronization, signalling and control symbols. Each 20ms frame of data is divided into three time slots and each time slot contains information destined for one of three mobile stations. Thus, a particular mobile station only needs to turn on its receiver for one-third of the time since the data for the particular mobile station is confined to one of three time slots that make up the frame. In the reverse direction, the 20ms frame is likewise divided into three time slots. Each mobile transmitter uses only one of the two time slots in which it is not receiving, which leaves the other third of the time which can be utilized to scan other base station frequencies to see if another base station is received more strongly. These signal strength measurements are reported over the uplink channel to the current base station, which makes a decision on whether to hand off communications with that mobile station to a stronger base station. Utilizing signal strength measurements performed by mobile stations in making handoff decisions is called "Mobile Assisted Handover" (MAHO).

In this prior art system, it can be seen that a mobile transmits for only one-third of the available time and therefore has to use three times the peak power that otherwise might have been sufficient if continuous transmission had been employed. If continuous transmission had been employed, all three mobile transmissions would be overlapping in time and would therefore have to be given different frequency channels as in the British Army's PTARMIGAN SCRA system. Furthermore, transmit/receive duplexing filters would be

needed to allow simultaneous transmission and reception in the mobile station.

At the present time, there are many proposals to launch orbiting satellites which would support communication with mobile or handheld phones. While a high percentage of calls would be between fixed (PSTN or wireline) subscribers and satellite terminals, a percentage of calls would be between pairs of satellite terminals. In the latter case, it is desirable to avoid the double delay of the signal propagating from one terminal to the satellite; being relayed by the satellite to a ground network switch; back from the switch to the satellite and finally from the satellite to the second terminal. With this method, the signal propagates over four times the earth-satellite distance, increasing speech delay. It is therefore desired to provide a means of connecting one mobile terminal with another by means of a single satellite relay path using a mobile-to-mobile transponder. When using the inventive asymmetrical TDMA or TDMA/FDMA system disclosed in the parent application, a prior art transponder in the satellite would relay a signal received using the transmit format of one mobile terminal in the incorrect format to be received by the second mobile terminal.

For mobile-to-mobile calls, if the satellite transponder is merely programmed to transparently reflect to a second mobile station the signal received from a first mobile station and vice versa, then the mobile stations will also need to be capable of receiving narrowband TDMA signals which would increase their complexity. Alternatively, if the satellite receives narrowband TDMA signals decodes them and then recodes them into a wideband TDMA format for retransmission, the amount of processing required on

board the satellite to achieve a significant mobile-to-mobile capacity may become excessive. Thus, there is a need for a method and apparatus for supporting mobile-to-mobile calls in a satellite communication system which does not significantly increase either the complexity of the satellite relay station or the mobile stations.

## Summary of the Disclosure

It is an object of the present invention to overcome the above-described deficiencies in the prior art by providing an innovative method and apparatus for supporting mobile-to-mobile calls in a satellite communication system.

According to one embodiment of the present invention, a method for supporting calls between two mobile stations within a satellite communication system is disclosed. First, when signals transmitted by a first mobile station using a narrowband transmission format are received at a satellite relay station, the received signals are sampled and digitized. The sampled and digitized signals are then stored in a buffer at a first rate. The stored data is then read out of the buffer at a faster rate than the first rate and modulated onto a downlink frequency to create a wideband transmission format. The modulated signals are then transmitted to the second mobile station.

According to another embodiment of the present invention, a satellite transponder for supporting calls between two mobile stations within a satellite communications system is disclosed. The transponder comprises receiving means for receiving signals from a first transmission format. The received signals are sampled and digitized in sampling and digitizing means and stored in a buffer at a first rate. The stored

signals are then read out of the buffer at a faster rate than the first rate and are modulated in a modulating means onto a downlink frequency to create a wideband transmission format. Transmitting means then transmit the modulated signals to a second mobile station.

## Brief Description of the Drawings

The present invention will now be described in more detail with reference to preferred embodiments of the invention, given only by way of example, and illustrated in the accompanying drawings in which:

Figure 1 illustrates a prior art TDMA format;

Figure 2 illustrates a TDM/FDMA format with overlapping mobile transmissions according to one embodiment of the present invention;

Figure 3 illustrates a TDM/FDMA hybrid format according to one embodiment of the present invention;

Figure 4 illustrates a TDM/FDMA hybrid format according to one embodiment of the present invention;

Figure 5 illustrates the application of the present invention to satellite communications with a large number of time slots;

Figure 6 illustrates a 3-cell frequency re-use plan;

Figure 7 illustrates a block diagram of a portable radio according to one embodiment of the present invention;

Figure 8 illustrates a base station for one embodiment of the present invention;

Figure 9 illustrates satellite/mobile communications in one embodiment of the present invention;

Figure 10 illustrates a satellite transponder according to one embodiment of the present invention;

Figure 11 illustrates a hub-to-mobile satellite transponder;

Figure 12 illustrates a mobile-to-hub satellite transponder; and

Figures 13a-b illustrate additional components for providing direct mobile-to mobile transponding according to one embodiment of the present invention.

## Detailed Description of the Preferred Embodiments

In a 3-slot TDMA communication system where the Mobile Assisted Handover feature is not required, but where simultaneous transmitting and receiving is to be avoided so as to eliminate the transmit/receive duplex filter, the present invention extends the transmit duty factor from one-third to two-thirds, thus halving the peak power requirement. The uplink and downlink formats according to the present invention are illustrated in Figure 2.

As illustrated in Figure 2, two of the three mobile transmissions overlap at any one time. In order to permit them to overlap in time, they must be made orthogonal, i.e., non-interfering, in some other domain such as the frequency domain. Since using twice the time for transmission allows the transmission data rate to be halved, it is possible to accommodate two transmissions within the same bandwidth by arranging that one of the transmissions uses the top half of an allocated bandwidth while the other transmission uses the bottom half, or vice versa. For example, a first mobile station may use the upper half of the channel bandwidth and halfway through its two-thirds transmit period a second mobile station can start transmitting in the lower half of the channel. Then, after a further one-third of the frame period, the first mobile station will finish using the upper half of the channel and a

third mobile station can begin transmitting in the upper half channel. After a further one-third period, the second mobile station will finish using the lower half channel, and the first mobile station can start transmitting again. However, the first mobile station will be operating on the lower half channel instead of the upper half channel it originally operated on. This problem arises only when an odd number of time slot are used in combination with channel bandwidth division by an even number, and may be solved by either of the two methods described below.

The solution in which two mobiles use the upper and lower half channels respectively for two-thirds of the time while a third mobile station uses the upper half channel for its first third of the time and then switches to the lower half channel for its second-third of the time is avoided since the aim of any solution should be that all mobiles function identically independent of time slot. It is preferable, if frequency switching midway through the transmit burst is to take place in any mobile station that it takes place in all mobiles so that the system has a uniform design.

Figure 3 illustrates one embodiment of the present invention in which a first mobile station receives a first third of the base station transmission and then transmits to the base station using the upper half of the uplink channel for the first one-third of its two-thirds transmit period. After the first third transmit period, the first mobile station switches frequency so as to use the lower half channel for its second one-third transmission period. Meanwhile, a second mobile station has received the second third of the base station's 40ms frame and starts transmitting in the upper half channel when the first mobile switches to the lower half channel. Then, when the second mobile

station switches to the lower half channel midway through its transmit burst, a third mobile station begins transmission in the upper half channel. When the third mobile station switches to the lower half channel, the first mobile station begins transmitting again in the upper half channel. The mid-burst frequency switch from the upper to lower half channel is preferably accomplished not by means of a fast switching frequency synthesizer, but rather by means of applying a systematic phase rotation to the transmitted signal in order to provide a plus or minus frequency offset from the center of the channel. This can be performed within the digital signal processing used for generating the modulation waveforms as will be discussed below.

A second embodiment of the present invention, which avoids a mid-burst frequency shift, is illustrated in Figure 4. Here, a first mobile station first transmits in the upper half channel and halfway through its two-third transmit frame a second mobile station starts transmitting using the lower half channel. Midway through the second mobile station's transmit period, the first mobile station finishes transmission and a third mobile station begins transmitting using the upper half channel. Midway through the third mobile station's transmit period, the second mobile station finishes its transmission on the lower half channel. At this time, the first mobile station begins transmitting again on the lower half channel which is opposite from the channel it initially used. In this embodiment, every mobile functions identically but alternates between transmitting in the upper and lower half channels on successive bursts. In this system, the one-third receive period of 13.3ms between successive bursts is available for changing the transmit frequency, which can

be accomplished by using a frequency synthesizer with a modest frequency changing speed.

It will be appreciated that the invention is not limited to a system with three time slots. When an even number of time slots is used, for example four, and the mobile transmit time is three-fourths of a frame, the transmissions of three mobile stations overlap in frequency at one time. In such a situation, the channel bandwidth can be divided into three, and each mobile station can then use the three subbands in sequence. Alternatively, one mobile can transmit for 2/4 of the time in 1/2 of the bandwidth, while the other three use the other combinations of half-frame period and half-channel-bandwidth.

The above described solutions are in general characterized by dividing the uplink channel bandwidth into a number of subbands which is at least one less than the number of downlink timeslots 'N'. For example, the three-timeslot case divides the channel into upper and lower halves, while the four-timeslot case divides the channel into three subbands. This is compatible with the reduction in bit rate by the factor (N-1) when the transmitter operates for N-1 timeslots instead of just one timeslot. When N is small, it is difficult to divide the number into N sub-bands without also reducing the bit rate by N instead of only N-1. For example, in the three-timeslot system, it would be difficult to accommodate a half-bit rate transmission, obtained by transmitting only 2/3rds of the time instead of 1/3rd, in only 1/3rd of the bandwidth. This difficulty however disappears when N is large.

Figure 5 illustrates one embodiment of the present invention which may be advantageous for satellite-mobile communications. In this embodiment, a 512-slot TDM downlink is combined with a 512-subband FDMA uplink. To

avoid using a duplex filter in the mobile station, the signal for transmission is compressed into the 511/512ths of the time remaining over after the mobile has received its 1/512th of the downlink TDM format. However, the 0.2% increase in the information rate does not hinder it from being accommodated in 1/512th of the bandwidth. Without this signalling format, either the mobile would have to transmit and receive at the same time, necessitating a duplex filter which results in undesirable signal losses, or else use TDMA on the uplink involving the mobile transmitting, for example, for 1/512th of the time using 512 times the peak power which results in an undesirable increase in the peak power and current requirements from the power supply. The present invention may, of course, also in such a case permit transmission for 510/512 of the time or even less, without severe difficulties, the compression of the information not being restricted to clearing one timeslot for receiving if there are other demands on time, such as providing guard times between transmit and receive.

It can also be advantageous to consider other hybrids of TDMA and FDMA and even CDMA for the uplink in the case of satellite communications. Satellites orbiting at altitudes which are lower than the geostationary altitude exhibit significant velocities relative to stationary or mobile terminals on the ground. This can result in the Doppler shifts of the frequency received at the satellite from the ground terminals that are significant compared with the narrow transmission bandwidths of a pure FDMA uplink. It is therefore sometimes desirable to increase the uplink bandwidth to make Doppler shift relatively insignificant, without reducing the capacity of the system. A small factor increase, such as 2,4 or 8 may

often suffice. One method of accomplishing a 2:1 increase in bandwidth while accommodating the same number of transmitters would be for each uplink transmission to be compressed into 256/512ths of the time on one of 256 available subbands; two transmissions in each subband would then be accommodated by TDMA through a first mobile station's transmitter using the 1/512th timeslots numbered 1 to 256 and a second mobile station's transmitter using timeslots 257 to 512. The first mobile station receives on timeslot 257, while the second mobile station receives, for example, on timeslot 1, thus avoiding the need for being able to simultaneously transmit and receive. This principle may be extended to 4 timeslots on each of 128 subbands, or 8 timeslots on each of 64 subbands, and so on. However, The mobile station's peak transmitter power must be increased as its duty factor is reduced by using more TDMA and less FDMA on the uplink.

The bandwidth may instead be expanded by the use of Code Divisional Multiple Access (CDMA) on the uplink. In CDMA, each of the original information bits is transmitted a number of times with or without a polarity inversion according to the bits of an access code. For example, a four-times increase in bandwidth is achieved by using the access code 1100 and transmitting, in place of the original bit B1, the sequence B1B1B1B1; B2 is also replaced by B2B2B2B2 and so on, giving a fourfold increase in bit rate. Another mobile transmission may be allowed to overlap this by use of a different access code, preferably an orthogonal code such as 1001. The other mutually orthogonal codes are 1111 and 1010, resulting in four, overlapping, non-interfering transmissions sharing a four times wider subband. This achieves a fourfold increase in uplink signal bandwidth which is desired to render Doppler shift relatively

insignificant while preserving capacity without requiring higher peak transmitter powers from the mobile station.

The capacity in a cellular telephone system or in a mobile-satellite communications system, depends on being able to re-use the limited number of allocated frequencies for more than one conversation. The service area to be covered is usually divided into a number of cells each served by a base station (or illuminated by a satellite antenna spot-beam). Ideally, it should be possible to utilize the whole of the allocated spectrum immediately in each adjacent cell, however this is not conventionally possible due to the interference of neighboring cells used in the same frequencies. As a result, a frequency re-use plan must be employed to control interference levels. For example, a so-called 3-cell frequency re-use plan may be employed, as illustrated in Figure 6. A 3-cell frequency re-use plan guarantees a certain minimum desired Signal-to-Interference (C/I) ratio that may suffice if adequate error-correction coding is employed on the transmitted signal. In general, the C/I is better for a 3-cell re-use plan in the satellite case than in the ground cellular case, due to the sidelobes of the satellite's cell illumination profile tapering off more rapidly out-of-cell than the signal strength reduction with increasing distance in ground propagation.

A problem can arise in applying frequency re-use plans to a TDM downlink. A limited allocated frequency spectrum has to be divided into three to permit a 3-cell re-use plan. As a result, the bandwidth of a full TDM solution can no longer be accommodated. This problem is solved according to an aspect of the present invention, by using a time-reuse plan instead of a frequency reuse

plan on the TDM downlink, combined with a corresponding frequency reuse plan on the FDMA uplink.

In the time-reuse plan, cells designated '1' in Figure 6 are illuminated from the satellite or from their respective ground base stations using the first 1/3rd of the timeslots in the TDM format, using the full available frequency spectrum. The cells labelled '2' then receive illumination during the second 1/3rd of the TDM format, and so-on. In this way, adjacent cells are not illuminated with the same frequencies at the same time, but the full TDM signal bandwidth is still transmitted. For example, in a 512 timeslot TDM format, cells numbered '1' are illuminated for the first 170 time slots. Each mobile terminal, after receiving its respective 1/512th time slot may transmit for the remaining 511/512ths of the frame using a designated one of the first 170 out of 512 uplink FDMA channels. The cells numbered '2' are then illuminated for the second 170 out of the 512 timeslots, and corresponding mobiles in those cells reply using FDMA and respective uplink channel frequencies 171 to 340. The cells numbered '3' then become illuminated for the third 170 out of 512 timeslots, and their mobiles reply on uplink frequencies 341 to 510. The remaining two timeslots can be reserved for illuminating all cells with a special signal used for paging and call set-up. Likewise, the two correspondingly unused uplink channel frequencies can be reserved for mobiles wishing to initiate contact with the system by performing a so-called random access.

By using the above system of time re-use plans on the downlink combined with a matching frequency reuse plan on the uplink, the described TDM/FDMA hybrid access method can be employed while controlling the interference levels between adjacent cells.

As previously disclosed, it can be desirable to widen the uplink channel bandwidths by employing TDMA or CDMA on the otherwise FDMA uplink and reducing the number of FDMA channels commensurately, in order to provide increased tolerance of Doppler shifts. It will be appreciated by those of ordinary skill in the art that the actual numbers used above are exemplary and do not imply a restriction of the present invention to those examples.

Figure 7 illustrated a preferred implementation of a mobile or portable radio suitable for use in the present invention. An antenna 10 which operates at both the uplink and downlink frequencies is connected alternately to receiver 30 and transmit power amplifier 120 by means of a T/R switch 20, which is controlled by the TDM timing generator 50. In the alternative, transmit/receive duplexing filters can be used if uplink and downlink frequencies are sufficiently separated to permit simple filters with low loss. When uplink and downlink frequencies are widely separated, a single antenna may not be efficient, in which case separate transmit and receive antennas may be necessary. This does not, however, change the principle of the present invention, which is to avoid having the transmitter active during receiving instances.

The timing generator supplies timing and control pulses to the switch 20, the receiver 30 and the digital demodulator and decoder 40 in order to provide them with power to select the signal in allocated timeslots on the downlink. The receiver 30 has sufficient bandwidth to receive the entire TDM downlink signal spectrum, but only one timeslot per TDM frame period of this bit rate stream is selected for processing in the digital demodulator and decoder 40. During this selected timeslot, the signal from the receiver is digitized in A

to D converter 31 and recorded in a buffer memory contained in the demodulator 40. The digitization technique preferably preserves the complex vector nature of the signal, for example, by splitting the real(I) and imaginary (Q) parts by means of a quadrature mixer, and then digitizing each part. An alternative to this so-called I, Q, or Cartesian method is the LOGPOLAR method described in U.S. Patent No. 5,048,059 which is assigned to the same assignee and is hereby incorporated by reference. Another alternative technique is the co-called homodyne or zero-IF receiver such as described in U.S. Patent Application No. 07/578,251 which is hereby incorporated by reference.

The complex vectors recorded in the buffer memory are then processed by the digital demodulator and decoder 40 during the rest of the frame time before collection of the next timeslot's complex signal samples. The demodulation stage of the processing can involve channel equalization or echo-cancelling to mitigate the effects of multipath propagation. Typical algorithms suitable for this are disclosed in U.S. Patent Application Nos. 07/964,848 and 07/894,933 assigned to the same assignee which are incorporated herein by reference.

To help bridge fading, error-correction encoded data frames may be spread over more than one timeslot by means of interleaving, so that a number of timeslots have to be collected and deinterleaved before the first frame of speech data is error-correction decoded. The demodulation of the signal samples in each timeslot should preferably be optimized together with the error-correction decoding algorithm for best performance at low signal-to-noise ratios, for example, by passing soft-decision information from the demodulator to the decoder, or by combining demodulation with decoding in a

so-called decodulator, as disclosed in U.S. Patent Application No. 08/305,727, which is incorporated herein by reference.

After demodulation and error correction decoding, using for example, a soft-decision based convolutional decoder, a frame's worth of error-correction decoded speech data is passed to the speech coder/decoder 60, where it is turned into PCM speech samples at 8 kilo samples/second using a decoder that matches the encoder at the originating transmitter. The speech coding/decoding technique can for example be Residual Pulse Excited Linear Predictive Coding (RELP) or Code Book Excited Linear Predictive Coding (CELP) which compresses an 8 kilo sample/second PCM voice signal down to 4 kilobits/second at the transmitter, and conversely expands the 4 kilobits/second signal from the decoder 40 to 8 kilosamples/second PCM signal again for D to A conversion in D to A convertor 130 and audio amplification for driving an earphone 132.

In principle, the receiver only needs to receive a single frequency on which all signals from all mobiles are multiplexed and modulated. As a result, the receiver does not have to tune to alternative frequencies, but rather, selects between all available timeslots. The control microprocessor 110 receives information on a calling/paging slot during call set-up designating the slot to be used for the call. The control microprocessor 110 then programs the timing generator accordingly, to generate all control pulses necessary to power the receiver and transmitter on and off according to the inventive TDM/FDMA hybrid formats described herein. The control microprocessor also programs the transmit synthesizer 90 to generate a narrowband uplink frequency channel associated with the allocated downlink timeslot with the help of upconvertor

80. The upconvertor 80 can operate in several manners. First, the upconvertor 30 can operate by mixing a fixed modulated frequency (TX IF) with the variable frequency produced by a programmable frequency synthesizer to generate a sum or difference frequency at the desired transmit channel frequency, wherein either the sum or the difference is selected by a filter. In the alternative, the upconvertor 80 can operate by mixing a signal from a voltage controlled oscillator with the synthesizer frequency to produce a difference frequency that is phase-compared to the fixed modulated frequency in a phase error detector, the phase error then being amplified and applied to the VCO in order to lock it to the modulated TX IF, thus causing the VCO phase to follow phase modulation on the TX IF. The determination of which method to select depends on whether the selected transmit modulation technique is pure phase modulation, i.e., constant amplitude modulation, or whether the selected modulation involves a varying amplitude component.

In the reverse direction, a speech signal from the microphone 131 is first amplified and converted to 8 kilosample/second PCM using A to D convertor 13 and then compressed to a reduced bit rate using the speech coder 60. Speech compression techniques such as RELP and CELP that compress speech to as low as 4 kilobits/second generally operate on 40ms frames of speech samples at a time. A frame is typically compressed to 160 bits, that are then error-correction coded in digital encoder 70 before being modulated onto a radio frequency. The modulated radio frequency may be a fixed intermediate frequency locked to an accurate reference oscillator 100. The signal is then upconverted in upconverter 80 by mixing with transmit synthesizer 90 to the final uplink frequency signal which is then amplified by

transmit power amplifier 120 and passed by the switch 20 to the antenna 10. The digital encoder and modulator 70 includes buffering (and if used, interleaving) in order to compress the transmission into the available time left over after receiving the downlink timeslot, so as to implement the aspect of the present invention, thus avoiding simultaneous transmitting and receiving. The transmission may also be compressed into 1/4 or 1/8 of the frame period if it is desired to have 4 or 8 uplink timeslots. The timing of this compression, modulation, and activation and deactivation of the power amplifier at appropriate instances is also controlled by timing generator 50 so as to achieve the coordination between transmit and receive timing.

In some applications, the receiver may have to be able to tune to alternative channel frequencies as well as to select between the TDM timeslots on those channels. In those instances, the receiver 30 would also contain a frequency synthesizer programmed by control microprocessor 110 and locked to the accuracy of the reference frequency oscillator 100. The allocated frequency is given over a calling or paging channel at call set-up.

In landmobile radio applications using a push-to-talk operation, the mobile terminal may be a member of a group or net of correspondents sharing a trunked radio system with other groups. In trunked systems, all idle radios listen to a call set-up channel. When a radio transmits by activation of the talk switch, a short message is transmitted on the corresponding call set-up uplink channel requesting a channel allocation. The receiving base station network immediately replies on the downlink call set-up channel with a currently idle frequency/timeslot allocation to which the mobile terminal then adapts for the rest of the transmission.

When the press-to-talk switch of the transmitting radio is released, an end of message signal is transmitted to expedite the reversion of the base network and other members of the group to idle mode in which they listen to the call set-up channel. This procedure is fast and automatic, within a fraction of a second, so that it is completely unseen to the human operators.

In cellular or satellite telephone applications, idle mobile terminals listen to a particular timeslot/frequency designated by the calling/paging channel. Moreover, transmissions on the calling/paging channel timeslot may be further submultiplexed to form less frequently repeated slots each associated with particular groups of mobiles, designated, for example, by the last few digits of their respective telephone numbers. These so called sleep mode groups are only paged in a particular submultiplex slot, which control microprocessor 110 is able to identify from received data and can thus program the timing generator 50 to wake up the receiver only at these instances, which results in considerable standby power current consumption savings.

Furthermore, the digital demodulator/decoder 40 can, after processing of each new received timeslot, produce an estimate of the frequency error of the receiver caused by inaccuracies of the reference oscillator 100 as well as Doppler shift, which can be significant in satellite systems. By using broadcast information from a satellite, the microprocessor 110 can correct for the Doppler shift and determine the error due solely to reference oscillator 100. The microprocessor 110 can then correct the error by sending a correction signal such as a tuning voltage to the oscillator, in order to insure that the transmit frequency which is referenced to the reference

oscillator by transmit frequency synthesizer 90 is accurately generated. The process of correcting for Doppler shift involves determining the position or bearing relative to the satellite's orbit by utilizing any or all of the following parameters: measured rate-of-change of Doppler shift; satellite and antenna beam identification signals; broadcast information on the satellite's instantaneous three dimensional coordinates and amount of Doppler precompensation, if used; previous mobile terminal position; elapsed time since last position estimate; and mobile terminal velocity.

In addition to the frequency correction mechanism mentioned above, the demodulator produces information on the position of signal samples in the buffer memory deemed to correspond to known sync symbols, which yields information on the accuracy of the timing produced by the timing generator 50. The microprocessor 110 performs sanity checks on this information and then uses it, if deemed valid, to demand small timing corrections of the timing generator 50 so as to correct for any drift.

Figure 8 illustrates a block diagram of a base station implementation suitable for use in the present invention. A common antenna 210 is connected to a receiver low noise amplifier 230 and a transmit power amplifier 260 by a duplexing filter 220. The low noise amplifier passes the entire uplink frequency band to a bank of FDMA channel receivers 240. After digitizing the signal in each channel using one of the aforementioned complex vector digitizing techniques, the signals are processed in a bank of receive Digital Signal Processing devices 520 in order to perform demodulation and equalizing, error correction decoding, and speech decoding for each active channel. The resulting 8 kilosamples/second speech signals are then

time multiplexed using a standard digital telephone standard such as the T1 format for convenient connection to a digital switch or exchange 280 such as the ERICSSON AXE switch.

An alternative to the analog implementation of the FDMA receiver bank is to digitize the entire composite signal and to process it digitally to separate the individual FDMA signals. This is practical so long as the signal strength differences between the signals are not too great for the A to D convertor's dynamic range. Another aspect of the present invention is the inclusion of power control means to restrict the signal level differences between different FDMA signals in order to facilitate digital implementation of the FDMA receiver filter bank with potential simplification of the base station. The power control means proposed may be based on the mobile stations assuming correlation between the signal strength they receive from the base station and the signal strength the base station receives from them. Thus, an increase in signal strength received from the base station via the satellite is acted upon by a mobile station by reducing its transmitter power and vice versa. This is complemented by a slower power control means at the base station which includes up/down power control information in the signalling samples interleaved with voice symbols in each mobile station's timeslot.

The exchange/switch 280 selects between uplink signals received from satellite phones, calls received from the public switched telephone network, or signals from an operator or control room for transmission on the downlink, according to call set-up information, requested routing, or preset information. The switch 280 supplies the selected signals multiplexed together according to some known digital telephone trunk format

such as T1 and delivers the signals to the transmit DSP bank 270. The transmit DSP bank separately encodes each speech signal in the multiplex stream using a voice compression algorithm such as RELP or CELP. The transmit DSP bank then error correction codes the signals and remultiplexes the signals into the downlink TDM format for modulation using modulator 290 onto the downlink radio frequency and amplification using high power amplifier 260. The switch 280 also extracts call setup information for the uplink calling channels and inserts call setup information corresponding to paging slots in the downlink TDM format. This information is identified as data and not as speech to the respective DSP devices so that it bypasses RELP coding and instead is subjected to a more powerful form of error correction coding.

A land based system may furthermore include separate antennas and associated receive signal processing in order to effect space-diversity reception to improve range and to combat fading. The combination of signals processed from remote antennas with signals processed with antenna 210 can take place either within the demodulation and equalizing algorithm, or by means of a simple diversity selection on a speech frame by speech frame basis according to signal quality. Likewise, in the transmit direction, a second distant transmitter may receive signals from transmit DSP bank 270 for transmitting on the same frequency so as to improve area coverage. The mobile receiver illustrated in Figure 7 is able by means of its equalizing demodulator algorithm to perceive delayed signals received from a second transmitter as echoes of the first transmitter and to utilize these signals in order to improve reception. Satellite diversity may also be employed to improve communication reliability as

disclosed in U.S. Patent Application No. 08/354,904, which is incorporated herein by reference.

Figure 9 illustrates a block diagram of satellite communications system for one embodiment of the present invention. An orbiting satellite 410 is in communication with at least one ground station or outstations called the HUB 400 as well as with a number of portable mobile phones 420. The phones are each serviced by an appropriate antenna beam from a multiple spot-beam antenna on the satellite providing high gain in the direction of each phone. The HUB communicates with the satellite using, for example, C-band or Ka-band frequencies, while the satellite communicates with the phones using, for example, L-band (uplink) and S-band (downlink) frequencies. In most cases, most calls will be between satellite phones and ordinary phones belonging to the public switched telephone network. The HUB station accepts calls from the PSTN and relays them to the mobile phone via the satellite, and conversely accepts calls from the mobile phones relayed from the satellite and connects them to the PSTN. A small percentage of calls can be mobile to mobile calls, and the HUB may instruct the satellite transponder to relay them directly to each other without necessarily involving the PSTN. In some systems, two or more HUBS located in different parts of the world communicate with the same satellite. In this case, mobile to mobile calls may involve Hub-to-Hub connections which can be accomplished through international trunk lines that may be part of the PSTN system. Alternatively, the satellite HUB links can allocate some capacity for Hub-to-Hub communication via the satellite for such occurrences thus avoiding landline tariffs.

According to one embodiment of the present invention, mobile-to-mobile calls can be directly

relayed through a satellite relay station without using ground based hub-stations in order to avoid delay and external tariffs. A satellite transponder 500 according this embodiment of the present invention is illustrated in Figure 10. Signals transmitted by one of the mobile stations for the other mobile station are received at the satellite in receiver 510. The received signals are then sampled and digitized in an A to D convertor 520 and stored in a buffer 530 at a first rate. The stored signals can then be read out of the buffer 530 at a faster rate and modulated in a modulator 540 onto a downlink frequency to crate a wideband transmission format.

The sampling and digitization of uplink signals takes place in any case on board the satellite whenever the transponder is of the type known as a digital processing payload. Such a transponder may digitize the whole uplink bandwidth in order to subsequently use digital filters or a Fast Fourier transform technique to divide the bandwidth into sub-bands or all the way down to individual uplink channel frequencies. The transponder may use digitized signals also to affect digital beamforming as for example described in U.S. Patent Application No. 08/568,664, entitled "Efficient Apparatus for Simultaneous Modulation and Digital Beamforming for an Antenna Array," filed December 7, 1995, which is incorporated herein by reference. To form a mobile-to-mobile transponder according to the invention, digital bandsplitting and optionally digital beamforming is employed to split out one or more narrowband uplink channels for receiving mobile signals destined to be relayed directly to other mobiles. However, such directly relayed signals are preferably also relayed to the HUB station which continues to have responsibility for commanding the mobile transmitters to

adjust their power or timing and to accumulate tariffs to be charged to the subscribers for using the system.

When such digital processing payloads are used as described above, received signals from mobile stations are digitized using any of the aforementioned techniques described in incorporated references and are processed in a processor comprising memory elements and arithmetic elements. The HUB station provides a synchronization signal on the C- or K-band feederlink to determine, when the satellite mobile-to-mobile processing elements, an uplink frame period and timeslot timing (if TDMA is used on the uplink) during which samples from a mobile terminal will be digitized, processed and collected in the processor memory. The number of samples collected per frame in the processor memory will correspond to one uplink timeslot of signal duration. The HUB station will also monitor signals received from the mobiles relayed via the C- or K-band feederlink and issue timing adjustment commands if necessary, to control the mobile transmit timing such that signals are received at the satellite properly aligned in the determined timeslot.

The collected timeslot's worth of mobile uplink transmission is then read out of the memory according to a higher frequency clock and translated to a satellite-to-mobile downlink frequency by the downlink processing, beamforming and satellite transponder means such that it is transmitted in a downlink timeslot associated with the uplink channel and timeslot according to the principles of the parent application for associating a channel and timeslot of one TDMA format (e.g. narrowband TDMA) with a channel and timeslot of a different (e.g. wideband) TDMA format. A time compression of the relayed signal is thereby effected. The signal's bit allocation within the TDMA burst is not affected, nor is the nature of the modulation effected by this time

compression, only a scaling of time and bandwidth such that the relayed signal now matches the signal bandwidth and timeslot duration to which the mobile receivers are optimized. If necessary, a mobile that is allocated a direct mobile-to-mobile transponder channel changes the allocation of bits within the uplink burst as compared to the bit allocation that would be used for communication with the PSTN or via the HUB station. For example, incorporated Application No. 08/305,727 describes the advantages of using distributed pilot symbols together with a particular bit interleaving strategy for efficient communication over narrowband channels. However, the mobile receiver receives a wideband channel and processes only a short timeslot over which signal changes due to fading are negligible. In the wideband channel case, it can be more desirable to use non-distributed or "clumped" pilot symbols in the form of a known "syncword" that is centrally placed within the downlink timeslot. Accordingly, the mobile uplink transmission is changed to adopt the pilot symbol and interleaving bit placements of the downlink format, whenever a direct mobile-to-mobile channel is allocated.

A preferred format for satellite communications with dual-mode phones that operate in either the satellite system or the GSM land-based cellular system uses a satellite downlink with the same 200KHz channelization as GSM and a TDMA format that has the same burst duration and symbol rate as GSM, but a frame period that is either twice as long or four times as long as the GSM "full-rate" frame period, and therefore has either 16 or 32 timeslots compared to GSM's eight. In the uplink direction, the preferred format transmitted by the mobile terminal is a more narrowband format using 50KHz channelization and correspondingly fewer timeslots (four or eight), in order to reduce the

peak-to-average power ratio of mobile transmissions. In the uplink direction, the burst duration is chosen to be four times a GSM burst duration with exactly 1/4 the symbol rate, which format is easily created by the mobile transmitter using the components existing for the GSM cellular mode. The inventive format is described in more detail in U.S. Patent Application No. 08/501,575, entitled "Dual Mode Satellite/Cellular Phone," which is incorporated herein by reference.

The preferred format includes a superframe structure comprising a repeated pattern of twelve, 16-slot TDMA frames plus a 13th frame that contains Slow Associated Control Channel information (SACCH). The SACCH slots contain messages from the HUB to the mobiles enabling the HUB station to command mobiles inter alia to adjust their power or transmit timing. When a mobile terminal is connected directly to another mobile terminal using the inventive time-compressing transponder disclosed herein, it is appropriate for the SACCH commands to continue to be sent from the HUB to the mobile terminals in question rather than to require that one mobile have the ability to generate commands for another. Moreover, if two mobiles in direct connection attempted to control each other's transmit timing, their absolute timing would not be controlled to any system reference and would drift in an uncontrolled manner, risking timing clashes with other mobiles using other timeslots on the same frequencies. This is avoided by using the inventive time-compressive transponder to replace the samples in every 13th timeslot relayed to a mobile terminal with SACCH signal samples received from the HUB station via the C- or K-band feederlink. The uplink SACCH bursts received at the satellite from the mobile terminals continue to be relayed to the HUB station such that a two-way SACCH

message channel between each mobile station and its controlling HUB station is maintained even in the direct mobile-to-mobile communications mode. The HUB-originated SACCH slots thus provide the mobile stations with an absolute time reference relative to which the mobile station times its transmissions, avoiding the aforementioned drift problem. Timing is also maintained during periods of voice silence when the voice traffic slots are not transmitted in order to save satellite or mobile terminal battery power. Transmitting periodic signal bursts in order to maintain synchronization through periods of Discontinuous Transmission (DTX) is described in allowed U.S. Patent No. 5,239,557, which is incorporated herein by reference.

Thus, the mobile-to-mobile transponder preferably includes the steps of receiving narrowband signals from mobile stations and relaying them to HUB stations; digitizing some of the received narrowband signals and time compressing them for transmission back to other mobile stations in a wideband format; and multiplexing time-compressed signals into a wideband downlink TDMA format along with other signals received from the HUB station already in wideband format, such as SACCH messages destined for said mobile stations or voice or data traffic for PSTN-to-mobile calls. The multiplexed signals form a downlink TDMA signal structure which is then modulated onto a downlink carrier frequency. The modulated signals are then transmitted by a transmitter to the second mobile station. Thus, by buffering the received signals and reading the signals out of the buffer at a faster rate, it is possible to support mobile-to-mobile calls through a satellite relay station without having to significantly increase the complexity of either the satellite relay station or the mobile stations. The downlink power level is increased for

mobile-to-mobile calls to compensate for double-path radio noise, since the uplink noise was not removed by error correction decoding on board the satellite.

Figures 11 and 12 illustrate a satellite communications payload suitable for one embodiment of the present invention. Figure 11 illustrates the downlink to the mobile phones while Figure 12 illustrates the uplink from the mobile phones. Referring now to Figure 10, an antenna 360 receives a number of signals from the HUB which are demodulated or coherently downconverted using a bank of receivers 340. The receiver output signals are then coherently upconverted in a bank of upconvertors 320 by mixing with a common local oscillator 330. The upconverted signals are now at the downlink frequency and are amplified by a bank of power amplifiers 310, wherein each amplifier is coupled to one element, a group of elements, or a feed of a multi-beam antenna or phased array. In one embodiment of the present invention, the amplifiers are class C transmit power amplifiers operated at maximum efficiency. In one embodiment of the present invention, the satellite transmitter comprises saturated travelling wave tubes. The HUB is thus able by sending appropriate signals to the satellite antenna 360 to determine what signals will be broadcast by a multi-beam antenna 300 at what time and in what direction. In this manner, it can be determined, for example, that in any particular time slot of the down TDM format only a subset of regions of the earth receive the signals, the regions being sufficiently separated in boresight angle so that they do not suffer interference from one region to another. In this way, independent signals can be sent to one phone in each region in each timeslot without interference. In the next timeslot, a different set of regions, i.e., those in between the first set of

regions, are illuminated so that all regions receive the signal from some timeslots in the frame. Copending U.S. Patent Application No. 08/179,953, entitled "A Cellular/Satellite Communication System With Improved Frequency Re-use", filed January 11, 1994, which is incorporated herein by reference, discloses how one to one re-use can be used for the present embodiment wherein every timeslot is used in all of a number of sub-regions.

When the system is operating at less than full capacity, not all of the timeslots in the frame will be active. Moreover, one half of a two party conversation is generally silent at any time so that an advantage can be gained by turning off the signal in the corresponding timeslot momentarily. When the number of timeslots is large, i.e., 512, it is statistically accurate to assume that only approximately 50% will be active at the same time. The power amplifiers 310 are arranged to draw little or no current during inactive or unallocated timeslots so that the mean consumption from the satellite prime power supply corresponds, even when fully loaded, to only half the power amplifier peak power consumption. For a given size solar array, the power amplifier peak power can thus be dimensioned to twice the value which the solar array otherwise would support.

Furthermore, peak capacity is reached only at certain times of the day, whereas the solar array converts the sun's energy into electrical power during a full 24 hour period. By using a rechargeable battery to average the power consumption in 24 hours, a further factor increase in peak transmitter power can be made relative to the continuous load the solar array can support. An advantage of TDM downlink used in the present invention is that current consumption reduces in

direct proportion to the under-utilization factor, in contrast with an FDMA or CDMA downlink which use power amplifiers which only reduce their current consumption by the square root of the under-utilization factor, if at all. Therefore, using a TDM downlink allows the full benefit to be taken of the average under-utilization factor.

The active time slots of any TDM signal may be packed together to occupy adjacent time slots in a subframe period which is a portion of the TDM frame period. The inactive time slots form the rest of the TDM frame period. The subframe of any TDM signal retransmitted in one of the multiple satellite antenna beams does not overlap the subframes of the TDM signals transmitted in the neighboring beams.

Referring now to Figure 12, a multi-beam antenna or multi-element phased array 400 receives signals on the uplink frequency from a plurality of mobiles. Mobiles in the same region of the earth use different FDMA channel frequencies on the uplink and according to the invention do not transmit during their received timeslots on the TDM downlink. Mobiles in a different region of the earth use the same set of frequencies as mobiles in the first region, therefore the antenna 400 receives a plurality of signals on each FDMA channel that arrive from different directions. In the case of a multi-beam antenna such as a parabola with spaced feeds, the different directions correspond to different beams so that signals on the same frequency appear in different beams and can thus be separated. This may require that adjacent beams do not contain the same frequencies, but that an adequate re-use factor is employed such as the three to one frequency re-use pattern illustrated in Figure 6. When uplink FDMA channels are associated with corresponding downlink TDMA

timeslots, the use of a three-to-one time re-use pattern on the downlink as disclosed above automatically gives rise to a three-to-one frequency re-use pattern on the uplink, thus achieving separation of signals. On the other hand, a one-to-one re-use frequency pattern can be achieved for the uplink using the configuration of Figure 11 particularly when antenna 400 is a phased array.

The antenna 400, whether a multi-feed parabola or multi-element phased array, presents a number of RF ports containing a plurality of mobile uplink signals. A bank of low noise amplifiers 410 and downconvertors 420 amplify these signals and coherently downconverts them using a common local oscillator 470 to a suitable intermediate frequency for amplification and filtering. The downconverted filtered and amplified signals are then applied to a bank of upconvertors or transmitter modulators 430 which translate the signals to the C or Ka bank while preserving their phase relationships before adding them in a combiner 440 and amplifying them in a traveling wave tube TWT power amplifier 450 for transmission to the HUB station through an antenna 460. It should be noted that the antenna 460 in Figure 12 may be the same as the antenna 360 in Figure 11, the C/Ka bank receiver then being separated from the transmitter by means of a duplex filter. Moreover, both polarizations may be used in both directions in order to increase bandwidth utilization. Each polarization would then have associated with it half of the receiver bank 340 and half of the transmitter bank 430 connected to a separate traveling wave tube. Furthermore, a downlink antenna 300 and the uplink antenna 400 can also in principle be one and the same with the addition of transmit/receive duplexing filters for each beam, array

element or sub-array, thus achieving double use of the same antenna aperture.

A description of the corresponding HUB station equipment may be found in the aforementioned U.S. Patent Application No. 08/179,953, entitled "A Cellular/Satellite Communication System With Improved Frequency Re-use", which is hereby incorporated by reference.

To give the satellite transponder the ability to relay mobile-to-mobile calls directly, some processing on board the satellite in addition to that illustrated in Figures 11 and 12 is provided. Figures 11 and 12 represent the simplest and most flexible form of multi-beam satellite transponder, which operates by relaying everything received by every satellite receive antenna element to the HUB station for processing. When the receive antenna is a multi-element phased array for example, the combination of element signals to form a directive beam is done at the HUB station, and not on board the satellite, the signals not even needing to be digitized on board the satellite. For selecting a mobile signal on board the satellite for direct relay to another mobile terminal, the directivity must however be formed on board. It is also necessary to select out the narrowband uplink channel or channels that contain mobile transmissions to be transponded directly to other mobiles. If the satellite receive antenna forms its directivity by means of a parabolic reflector having multiple feedpoints for different receive beams, digital beamforming may not be required. It is also possible to provide a number of narrowband receiver channels using analog filter hardware that can be switched to connect to selected beams or tuned to select different channels under telecommand from the HUB station.

Alternatively, the satellite receive antenna may be a phased array and the array element signals then have to be combined on board the satellite in order to form directive receive beams. This is facilitated by digitizing the element signals and submitting them to a digital beamformer for processing using a number of beamforming coefficients. The coefficients can also be received by telecommand from the HUB station, where the coefficients can be adapted to maximize signal-to-noise-plus-interference ratios according to the method described in U.S. Patent Application No. 08/179,953, which has been incorporated herein. When such digitization and digital processing shall exist for beamforming, it can be logical also to employ digital channelization which uses digital filters to restrict the bandwidth for selecting individual uplink channels.

Figures 13a-b show the addition of the inventive mobile-to-mobile channels to the transponder of Figures 11 and 12, for example. The transponder of Figures 11 and 12 is configured to support PSTN to mobile connections without digital processing on board the satellite. This can make use of the complex, analog time-multiplexed feederlink disclosed in U.S. Patent Application No. 08/225,389, entitled "Large Deployable Phased Array Satellite," filed April 8, 1994, and may have the capability to provide different beamwidths as disclosed in co-filed patent application No. 08/225,399, entitled "Multiple Beamwidth Array," both of which are incorporated herein by reference. Alternatively, the satellite transponder may be of the full, digital processing payload variety which performs on-board digital channelization and/or beamforming. With either form of PSTN-MOBILE transponder alignment, the objective of the additions required to form the inventive mobile-to-mobile transponder is to bleed off some uplink

signals received from mobiles for filtering and time compression according to the inventive principles disclosed herein, and then to additively reinsert the time compressed signals for transmission to mobiles, multiplexed with other voice, data or SACCH signals received from the HUB via the feederlink receivers 340.

Figures 13a-b illustrate signals being received from mobile terminals using receive antenna elements connected to transponder 1000, which can be in one embodiment the same as shown in Figure 12. In addition to transponding the receive element signals to the HUB station via the feederlink the received element signal are, after amplification and downconversion also fed to digital processing unit 1001 which performs analog-to-digital conversion, digital channel filtering to split out selected uplink channel frequencies, and digital beamforming (if sufficient spatial selectively is not already provided by the antenna design). Digital beamforming and digital channelization can be performed in either order. Digital channelization is performed first in the case where different sets of beam directions shall be formed for different uplink frequencies, followed by per-frequency beamforming using different beamforming coefficient sets for each frequency. Digital beamforming may be performed first when the beam characteristics described are the same for all frequencies. It is also possible to have partial beamforming for sub-bands before further channel splitting of the sub-bands into individual uplink channels, followed by further beamforming processing to define offset direction sets for each channel or timeslot.

The signals separated by channel frequency (channel K) and direction (beam i) are stored as samples in buffer memory 1002 which is connected to digital

processing unit 1001. The samples corresponding to a desired uplink frequency and beam are selected by control and timing unit 1003 which also selects samples in a desired uplink timeslot, the timing of which is referenced back to the HUB station by means of synchronization signals received from the HUB using feederlink receivers 340. Selected samples corresponding now to a first mobile signal occupying a particular uplink timeslot, a particular uplink carrier and a particular direction of arrival (beam) are passed to a corresponding mobile-mobile transmit beamformer 1005 where they are processed to form antenna element signals that will create a directive transmit beam in a desired direction, i.e., towards a second mobile with which the first mobile is desirous to communicate. The samples are read out of transmit digital beamformer 1005 at a time determined by timing control unit 1003 such that they will be transmitted in an allocated downlink timeslot. Since downlink timeslots are shorter than uplink timeslots, the samples are read out of beamformer 1005 and into D-to-A convertors 1004 at a proportionally faster rate. Moreover, the complex samples can be accorded a progressive angular rotation corresponding to a desired frequency shift in order to assure that transmission occurs on a desired downlink carrier frequency, said frequency shift also optionally including precompensation of Doppler shift due to satellite motion to or from the destination mobile unit. The D-to-A converted, time-compressed and frequency shifted signals are added to other signals received from the HUB station by feederlink receivers 340, however, no signal will be received from the HUB in the timeslot and frequency channel allocated to the mobile-to-mobile downlink. The HUB station ensures this by not creating a corresponding feederlink signal at that instant. The

HUB station may, however, via control and timing unit 1003 inhibit particular timeslots received from a mobile, corresponding to its SACCH slots, from being selected from buffer memory 1002, so that the SACCH slots will not be added in adders 1006 and so will not be transponded from mobile-to-mobile. Instead, the HUB station fills in the downlink SACCH slot with SACCH information to be sent to the mobile.

The above describes how a single mobile signal is transponded to a second mobile. The hardware of Figure 13 is capable of performing the same function simultaneously for the reciprocal direction, and for many different such pairs of mobile terminals in different beams or frequencies or timeslots to a total number equal to the provided processing capacity for direct mobile-to-mobile calls. Where insufficient capacity for direct mobile-to-mobile calls may temporarily exist, mobile terminals may still be connected to other mobile terminals by the normal double-hop method of transponding their signals to the HUB station or stations and after switching through a mobile switching exchange or the PSTN transponding them back to other mobiles via the satellite. This has the disadvantage of double propagation delay, which the invention has sought to overcome. Mobiles initially allocated a double-hop path due to temporary lack of direct mobile-to-mobile transponding capacity may, however, be queued for allocation of a lower delay direct mobile-to-mobile link as soon as one becomes available due to earlier calls terminating. This queuing function is performed by the switching computer in the ground network and a pair of mobiles are switched from double-hop to single-hop connection by the HUB station issuing a so-called "internal handover" command using the SACCH channel. An internal handover comprises

sending a control message to the mobil informing it to change mode, channel or timeslot, and may be performed from time to time for other channel management reasons such as minimizing co-channel interference or avoiding timing clashes as is well described in the incorporated references, as well as for the purpose described above.

It will be appreciated by those or ordinary skill in the art that the number of timeslots, frequency bands and applications mentioned above are primarily for the purpose of illustration and are not meant to imply any limitation of the present invention. The present application contemplates any and all modifications that fall within the spirit and scope of the underlying invention disclosed and claimed herein.

CLAIMS:

1. A method for supporting calls between two mobile stations within a satellite communication system, comprising the steps of:

transmitting signals from a first mobile station to a satellite relay station using a narrowband transmission format;

sampling and digitizing signals received from said first mobile station;

storing said sampled and digitized signals in a buffer means at a first rate;

reading out of said buffer means said stored signals at a faster rate than said first rate and modulating said stored signals onto a downlink frequency to create a wideband transmission format;

transmitting said modulated signals to a second mobile station;

receiving and decoding said modulated signals at said second mobile station.

2. A satellite transponder for supporting calls between two mobile stations within a satellite communication system, comprising:

receiving means for receiving signals being transmitted using a narrowband transmission format;

means for sampling and digitizing said received signals;

means for storing said sampled and digitized signals at a first rate;

means for reading out said stored signals at a faster rate than said first rate and modulating said stored signals onto a downlink frequency to create a wideband transmission format;

transmitting means for transmitting said modulated signals to a second mobile station.

3. A method for supporting calls between two mobile stations within a satellite communication system, comprising the steps of:

receiving narrow band signals from said mobile stations at a satellite relay station;

relaying the received narrowband signals to at least one ground station;

digitizing some of the received narrowband signals;

time compressing said digitized signals;

multiplexing said time compressed signals into a wideband downlink format along with other signals from said at least one ground station;

transmitting said multiplexed signals to one of said mobile stations.

4. A method according to claim 3, wherein said other signals from said at least one ground station are SACCH signals.

5. A method according to claim 4, wherein said SACCH signals are computed based upon the received narrowband signals relayed to said at least one ground station.

6. A method according to claim 4, wherein said SACCH signals control transmit timing at said mobile stations.

7. A satellite transponder for supporting calls between two mobile stations within a satellite communication system, comprising:

means for receiving narrow band signals from said mobile stations at a satellite relay station;

means for relaying the received narrowband signals to at least one ground station;

means for digitizing some of the received narrowband signals;

means for time compressing said digitized signals;

means for multiplexing said time compressed signals into a wideband downlink format along with other signals from said at least one ground station;

means for transmitting said multiplexed signals to one of said mobile stations.

8. A satellite transponder according to claim 7, wherein said other signals from said at least one ground station are SACCH signals.

9. A satellite transponder according to claim 8, wherein said SACCH signals are computed based upon the received narrowband signals relayed to said at least one ground station.

10. A satellite transponder according to claim 8, wherein said SACCH signals control transmit timing at said mobile stations.

11. A method for supporting calls between two mobile stations within a satellite communication system, said satellite communications system having at least two modes of operation, a first mode of operation for directly connecting the mobile stations through a satellite relay station and a second mode of operation for directly connecting the mobile stations through the satellite relay station and a ground station, comprising the steps of:

receiving a call set-up request to connect said two mobile stations;

determining whether there is sufficient capacity for connecting the two mobile stations using the first mode of operation;

connecting the two mobile stations using the first mode of operation when sufficient capacity exists;

connecting the two mobile stations using the second mode of operation when it is determined that there is insufficient capacity;

queuing said call for a connection using the first mode of operation once capacity becomes available.

12. A method according to claim 11, wherein propagation delays in said first mode of operation are lower than propagation delays in said second mode of operation.

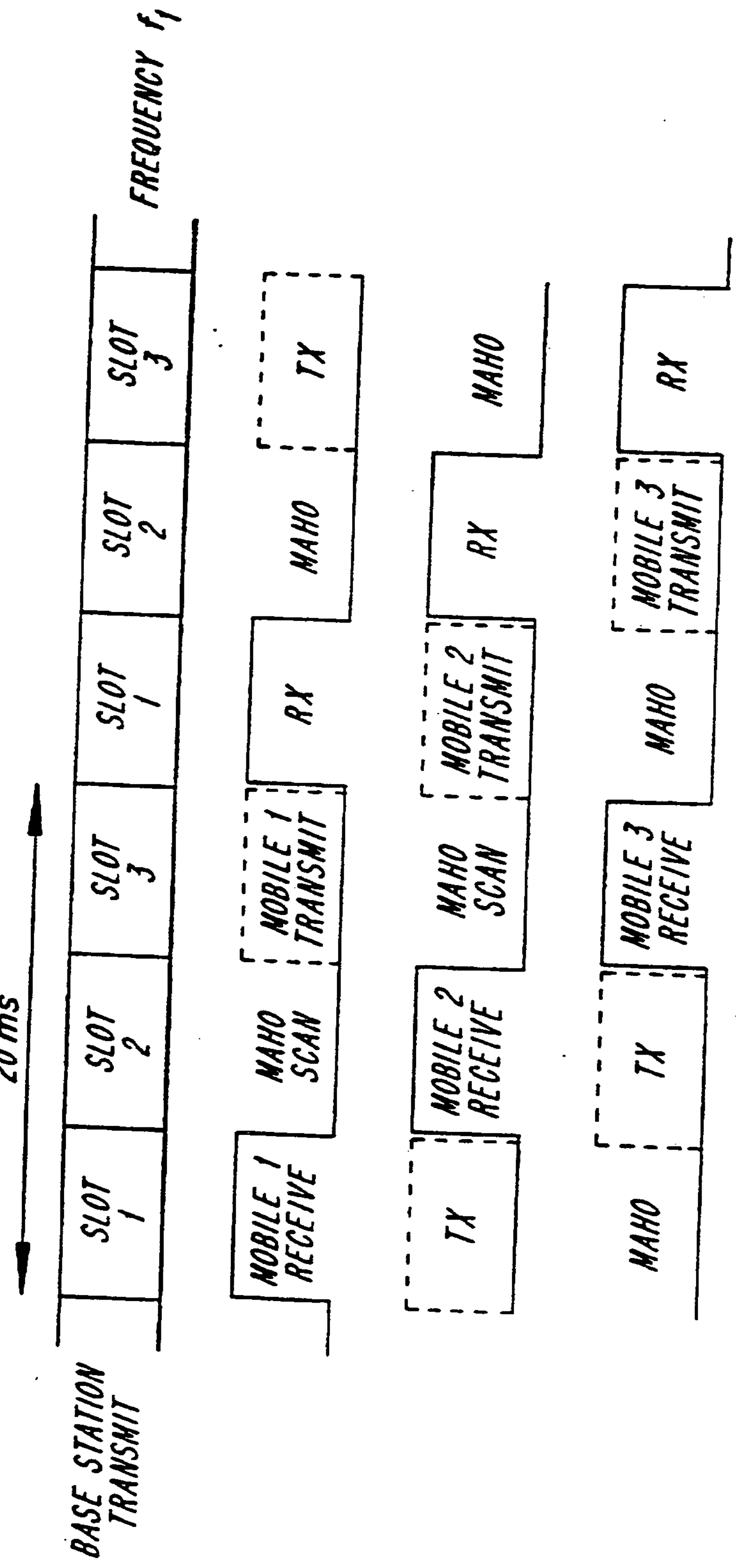



Fig. 1
(PRIOR ART)

Fig. 2

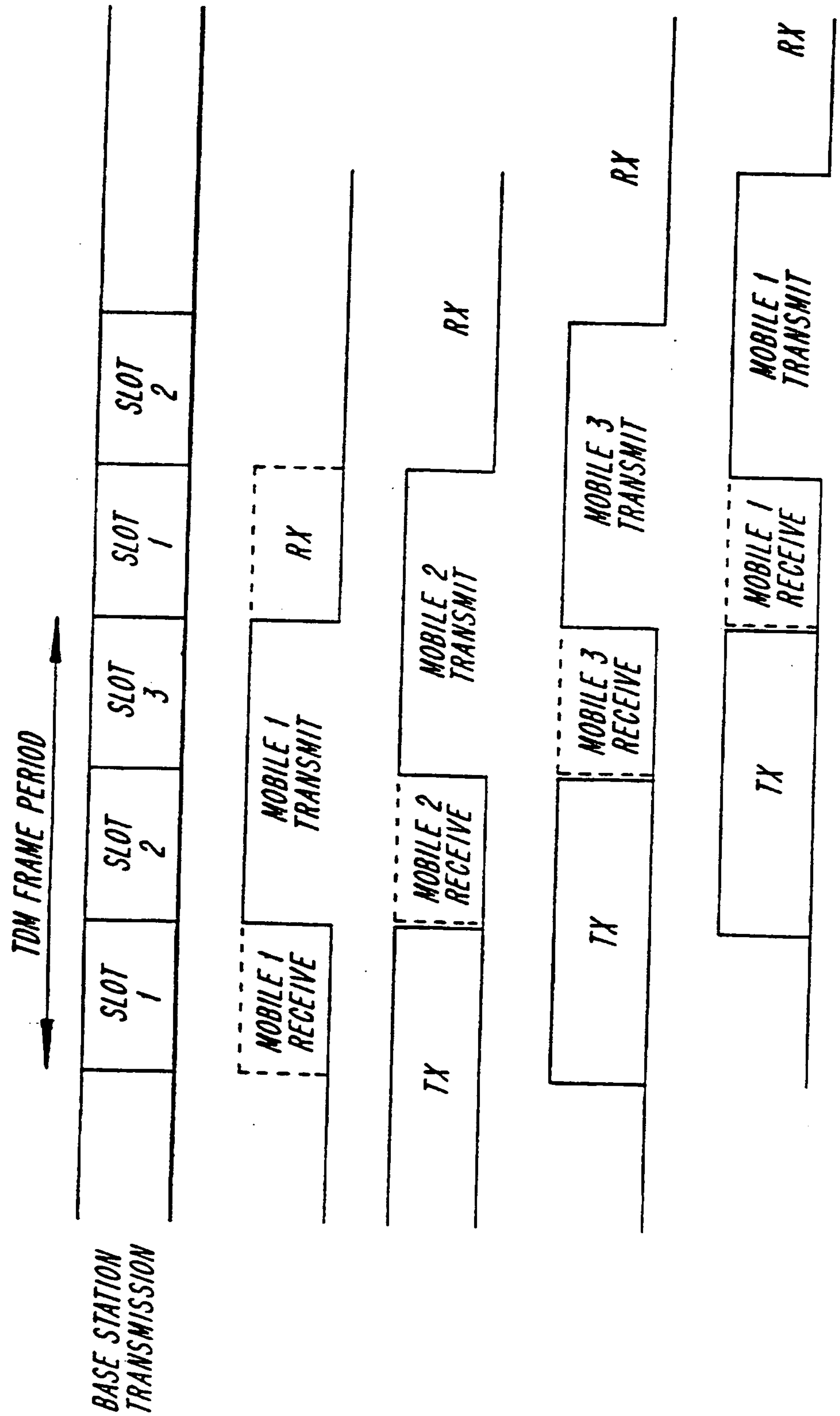

BASE STATION TRANSMISSION
TDM FRAME PERIOD
SLOT 1
SLOT 2
SLOT 3
SLOT 1
SLOT 2
MOBILE 1 RECEIVE
MOBILE 1 TRANSMIT
RX
RX
TX
MOBILE 2 RECEIVE
MOBILE 2 TRANSMIT
RX
TX
MOBILE 3 RECEIVE
MOBILE 3 TRANSMIT
RX
TX
MOBILE 1 RECEIVE
MOBILE 1 TRANSMIT
RX

Fig. 3

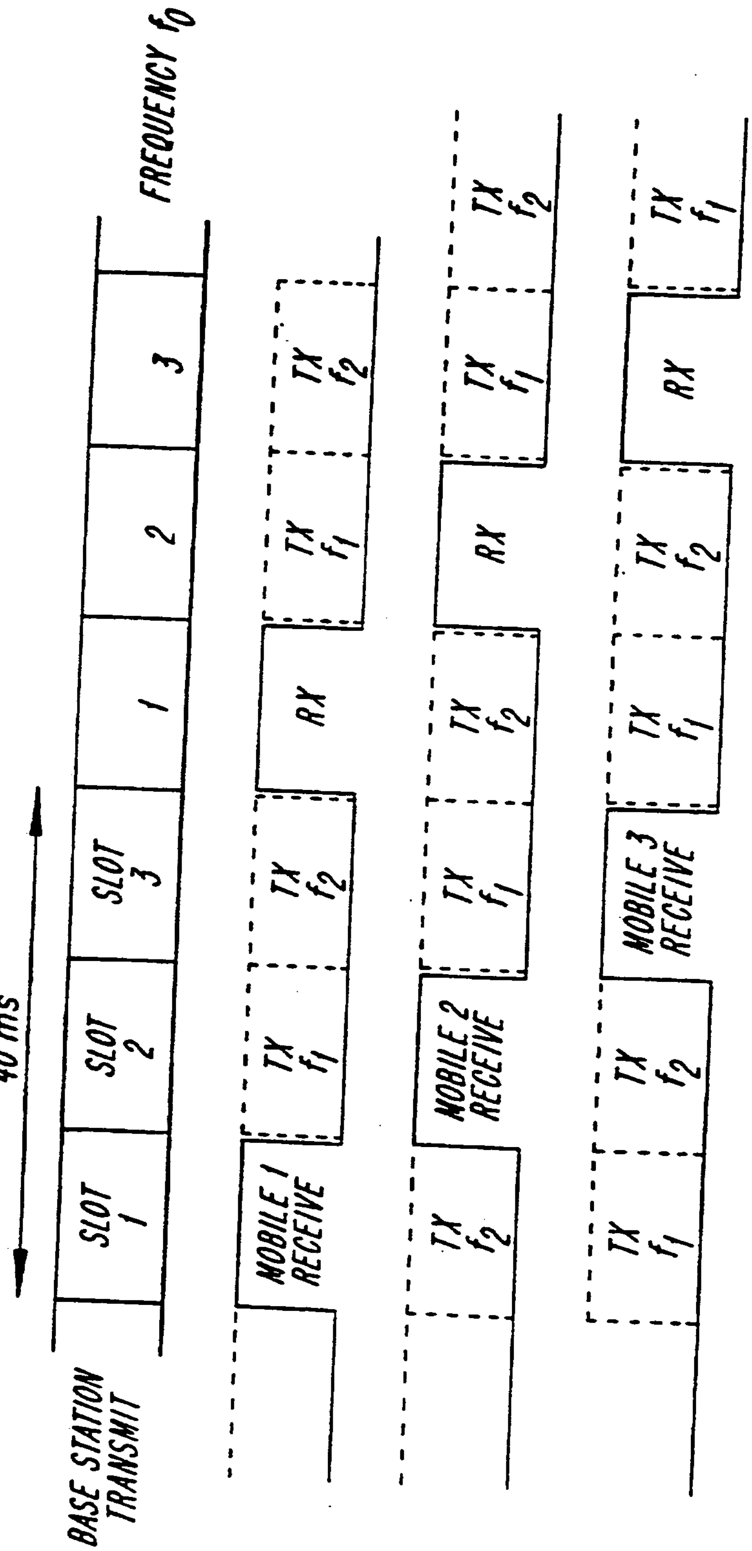

BASE STATION TRANSMIT
SLOT 1
SLOT 2
SLOT 3
1
2
3
FREQUENCY $f_0$
40 ms
MOBILE 1 RECEIVE
TX $f_1$
TX $f_2$
RX
TX $f_1$
TX $f_2$
TX $f_2$
MOBILE 2 RECEIVE
TX $f_1$
TX $f_2$
RX
TX $f_1$
TX $f_2$
TX $f_1$
TX $f_2$
MOBILE 3 RECEIVE
TX $f_1$
TX $f_2$
RX
TX $f_1$

Fig. 4

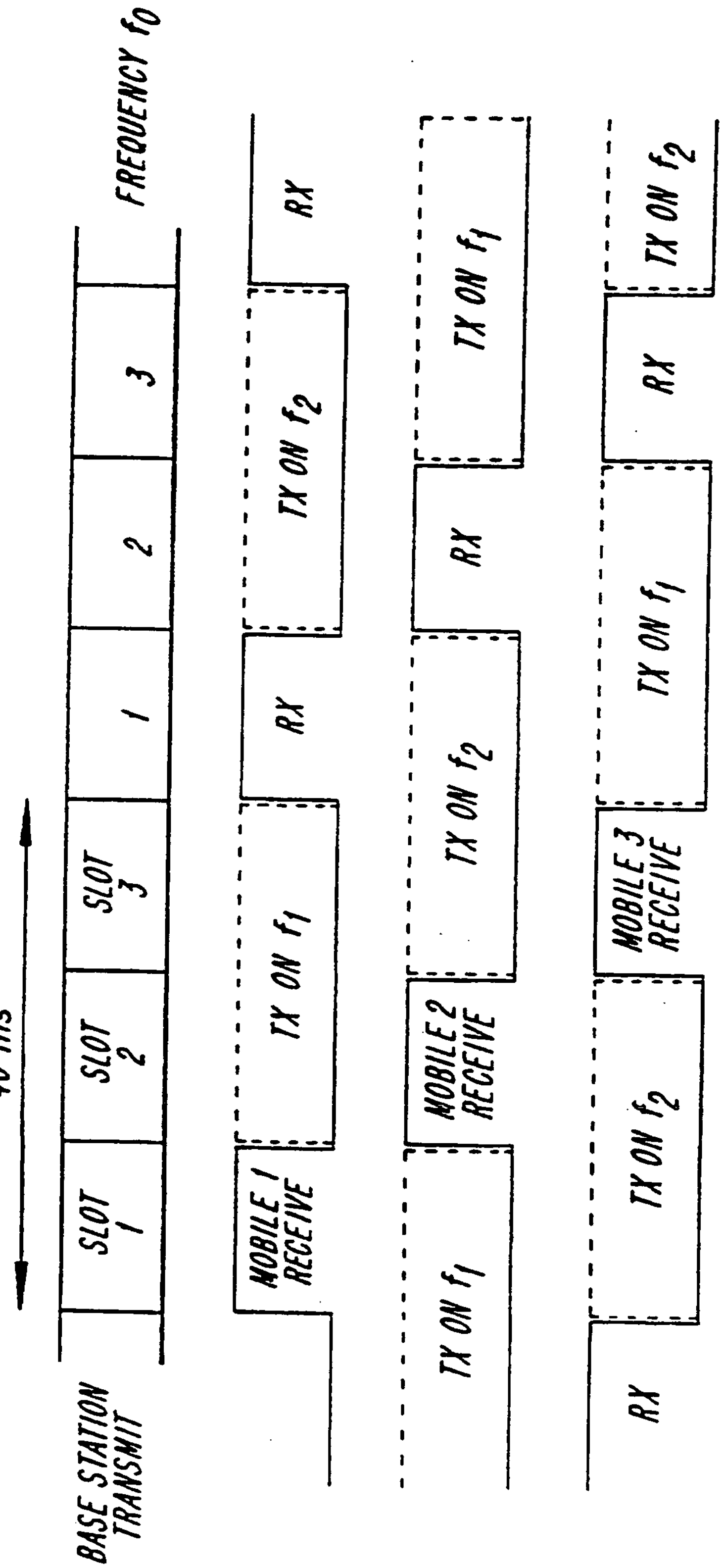

FREQUENCY $f_0$
BASE STATION TRANSMIT
SLOT 1
SLOT 2
SLOT 3
1
2
3
40 ms
MOBILE 1 RECEIVE
TX ON $f_1$
RX
TX ON $f_2$
RX
TX ON $f_1$
MOBILE 2 RECEIVE
TX ON $f_2$
RX
TX ON $f_1$
RX
TX ON $f_2$
MOBILE 3 RECEIVE
TX ON $f_1$
RX
TX ON $f_2$

Fig. 5

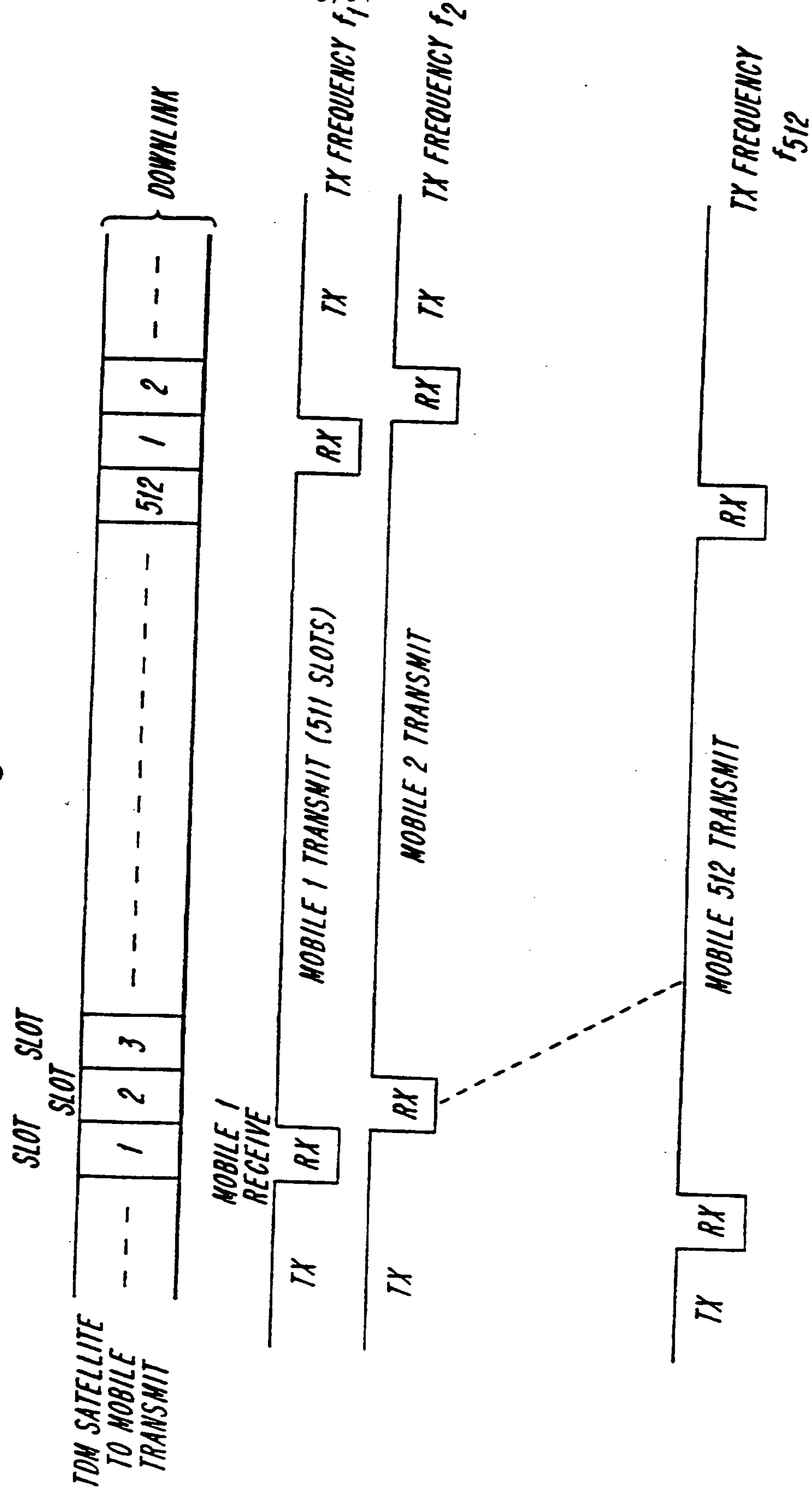
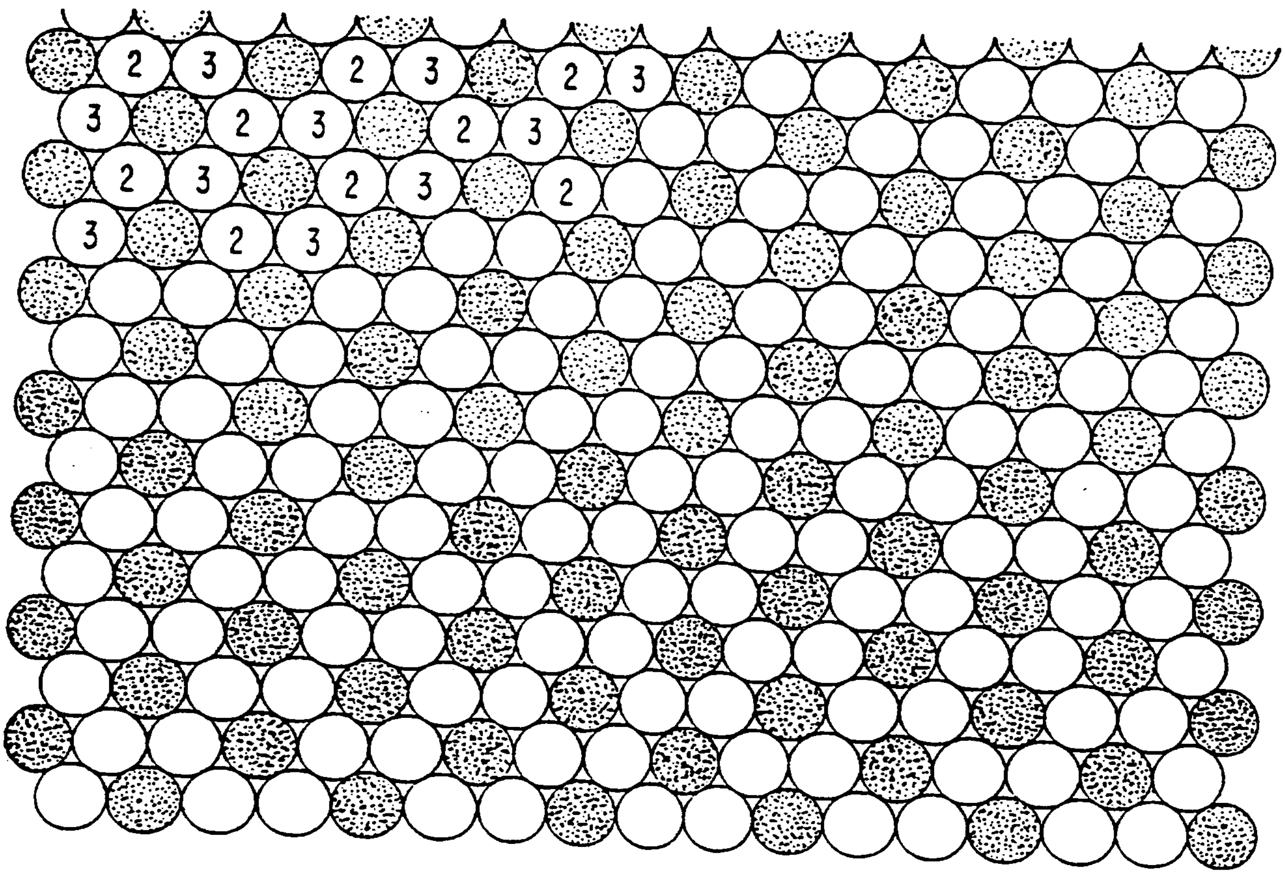

TDM SATELLITE TO MOBILE TRANSMIT
SLOT
SLOT
SLOT
1
2
3
512
1
2
DOWNLINK
MOBILE 1 RECEIVE
TX
RX
MOBILE 1 TRANSMIT (511 SLOTS)
RX
TX
TX FREQUENCY $f_1$
TX
RX
MOBILE 2 TRANSMIT
RX
TX
TX FREQUENCY $f_2$
TX
RX
MOBILE 512 TRANSMIT
RX
TX FREQUENCY $f_{512}$

Fig. 6



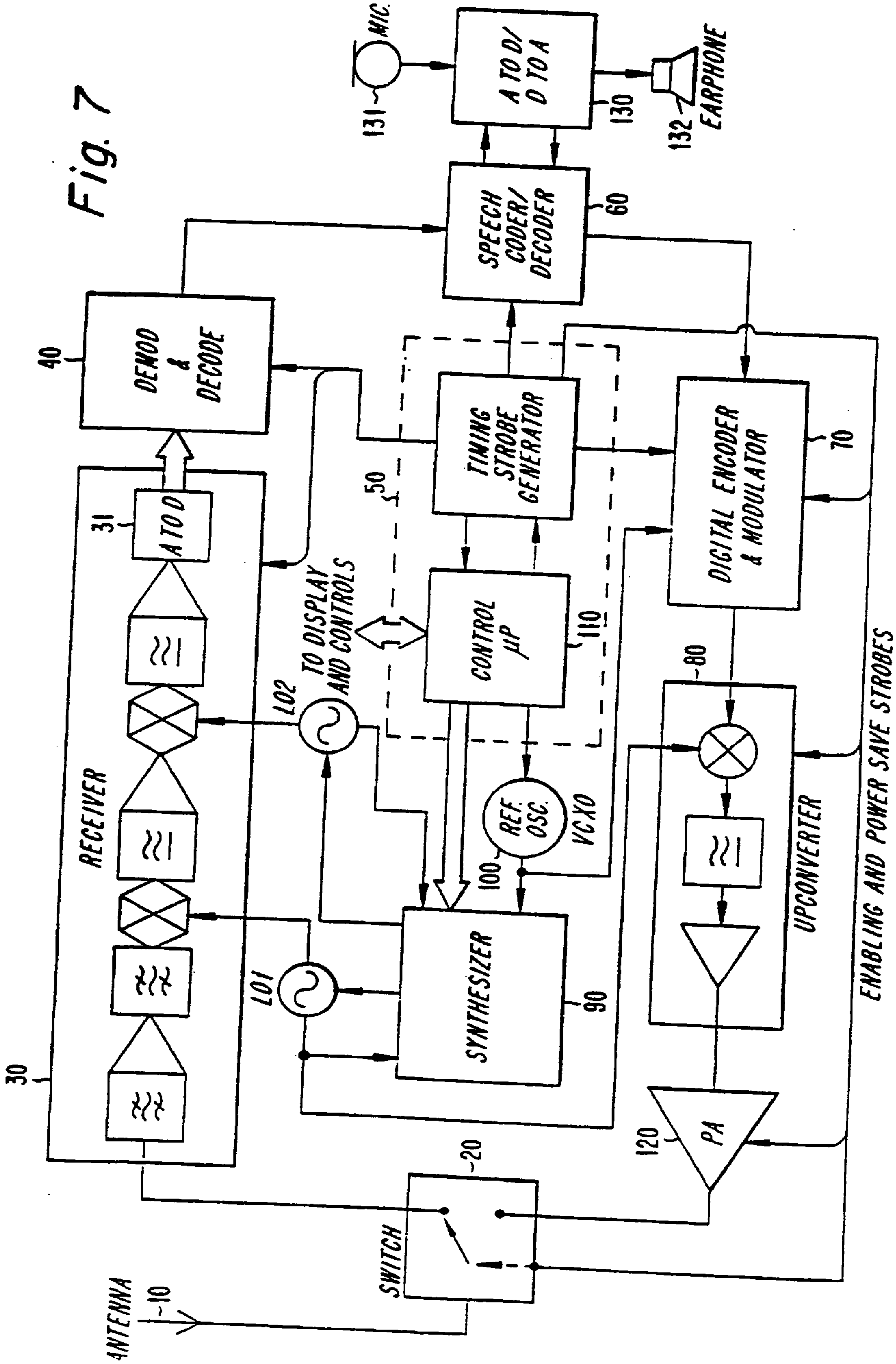

ANTENNA
10
SWITCH
20
RECEIVER
30
31
A TO D
DEMOD & DECODE
40
TIMING STROBE GENERATOR
50
SPEECH CODER/ DECODER
60
A TO D/ D TO A
130
MIC
131
EARPHONE
132
DIGITAL ENCODER & MODULATOR
70
UPCONVERTER
80
CONTROL μP
110
TO DISPLAY AND CONTROLS
LO2
LO1
SYNTHESIZER
90
REF. OSC.
100
VCXO
PA
120
ENABLING AND POWER SAVE STROBES

Fig. 7

Fig. 8

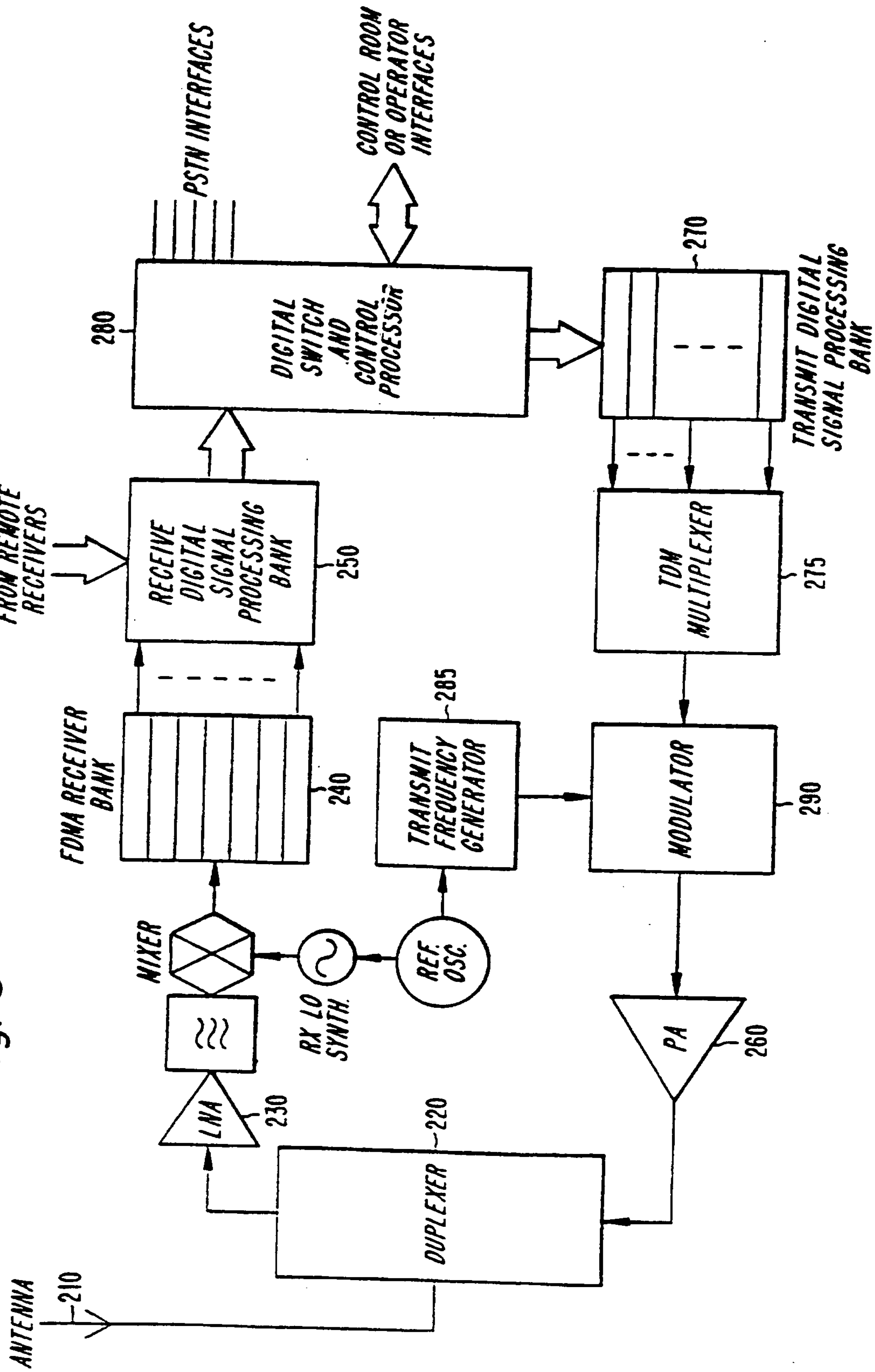

PSTN INTERFACES
CONTROL ROOM OR OPERATOR INTERFACES
DIGITAL SWITCH AND CONTROL PROCESSOR
280
270
TRANSMIT DIGITAL SIGNAL PROCESSING BANK
FROM REMOTE RECEIVERS
RECEIVE DIGITAL SIGNAL PROCESSING BANK
250
TDM MULTIPLEXER
275
FDMA RECEIVER BANK
240
TRANSMIT FREQUENCY GENERATOR
285
MODULATOR
290
MIXER
RX LO SYNTH.
REF. OSC.
PA
260
LNA
230
DUPLEXER
220
ANTENNA
210

Fig. 9

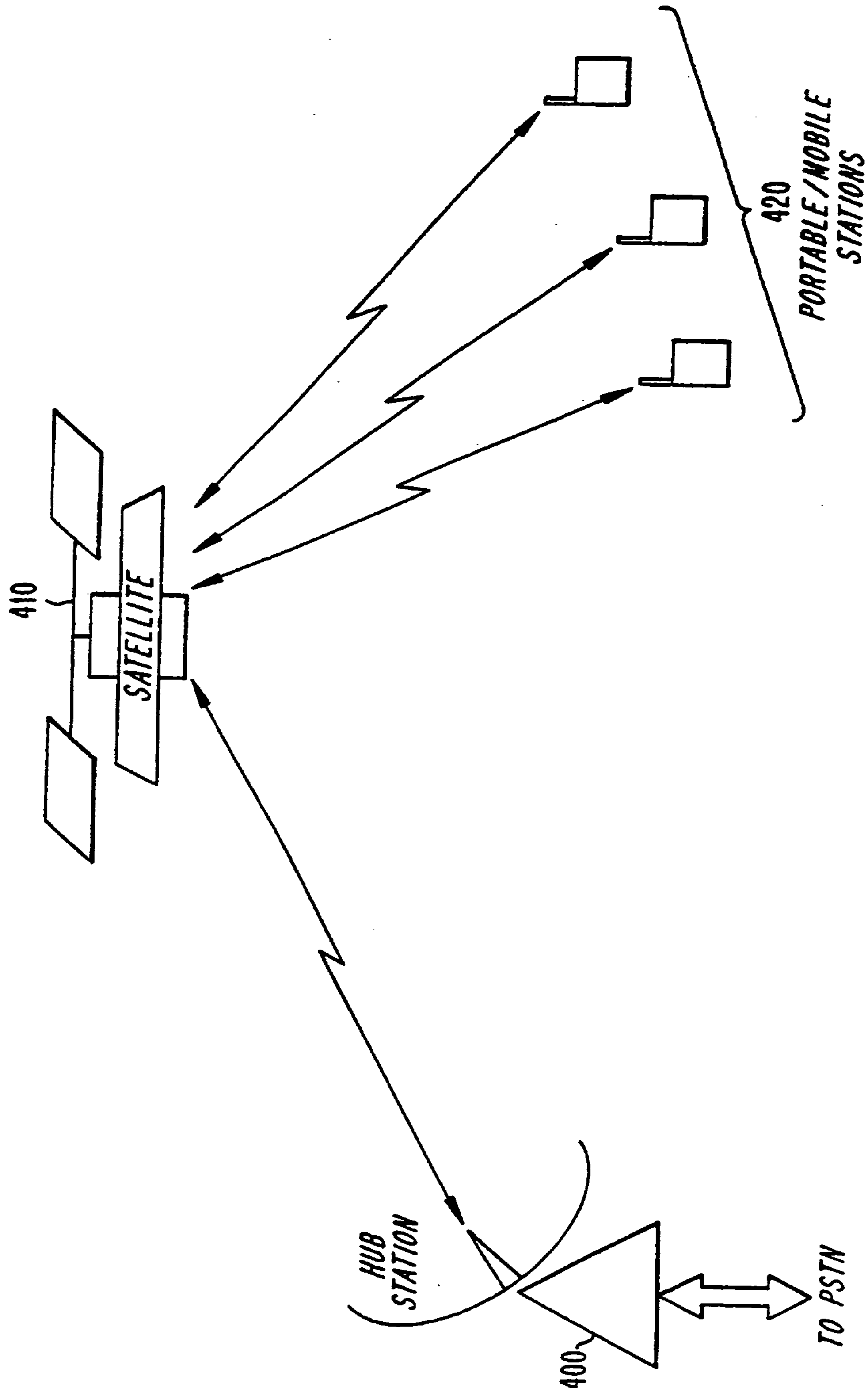
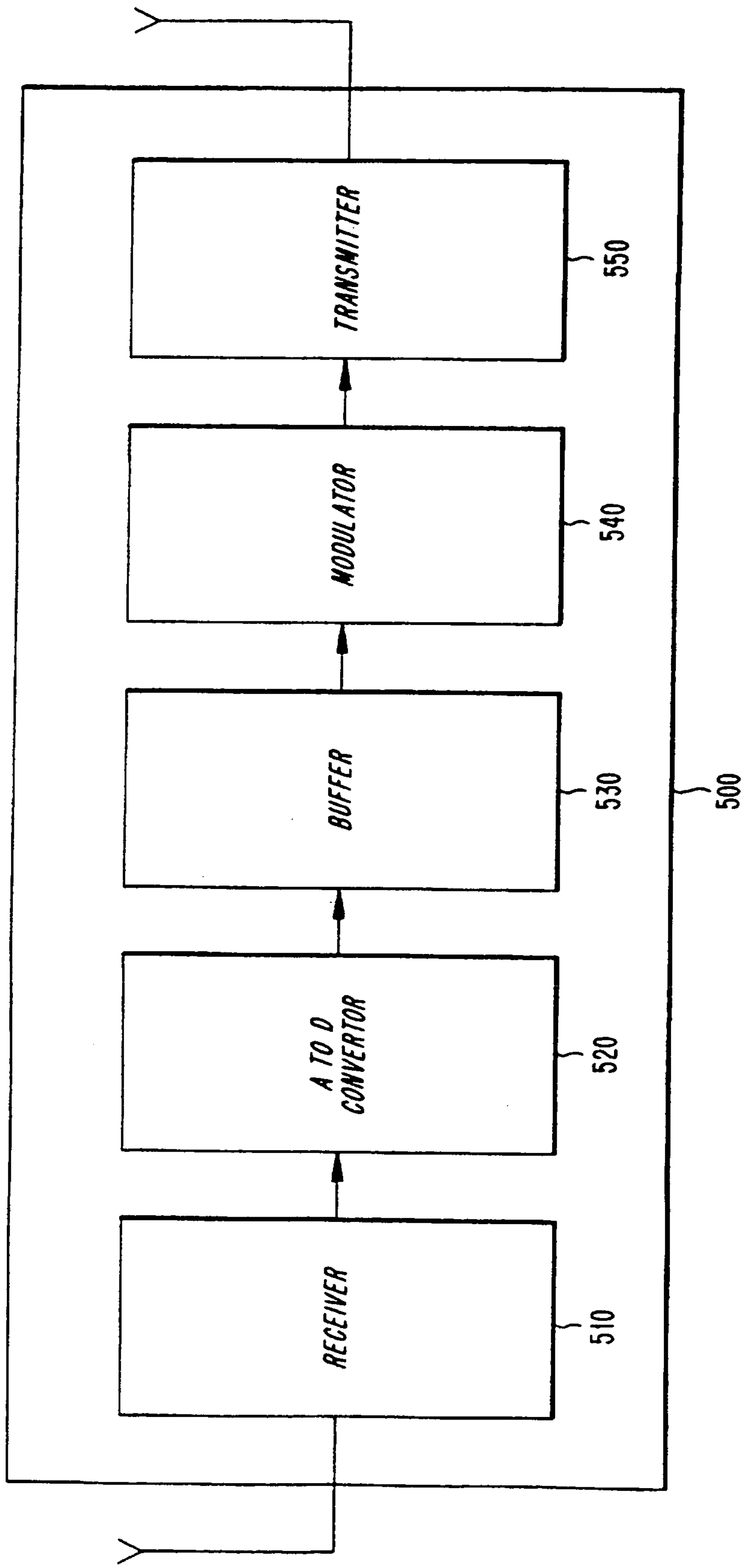

SATELLITE
410
420
PORTABLE/MOBILE
STATIONS
HUB
STATION
400
TO PSTN

Fig. 10


TRANSMITTER
550
MODULATOR
540
BUFFER
530
500
A TO D
CONVERTOR
520
RECEIVER
510

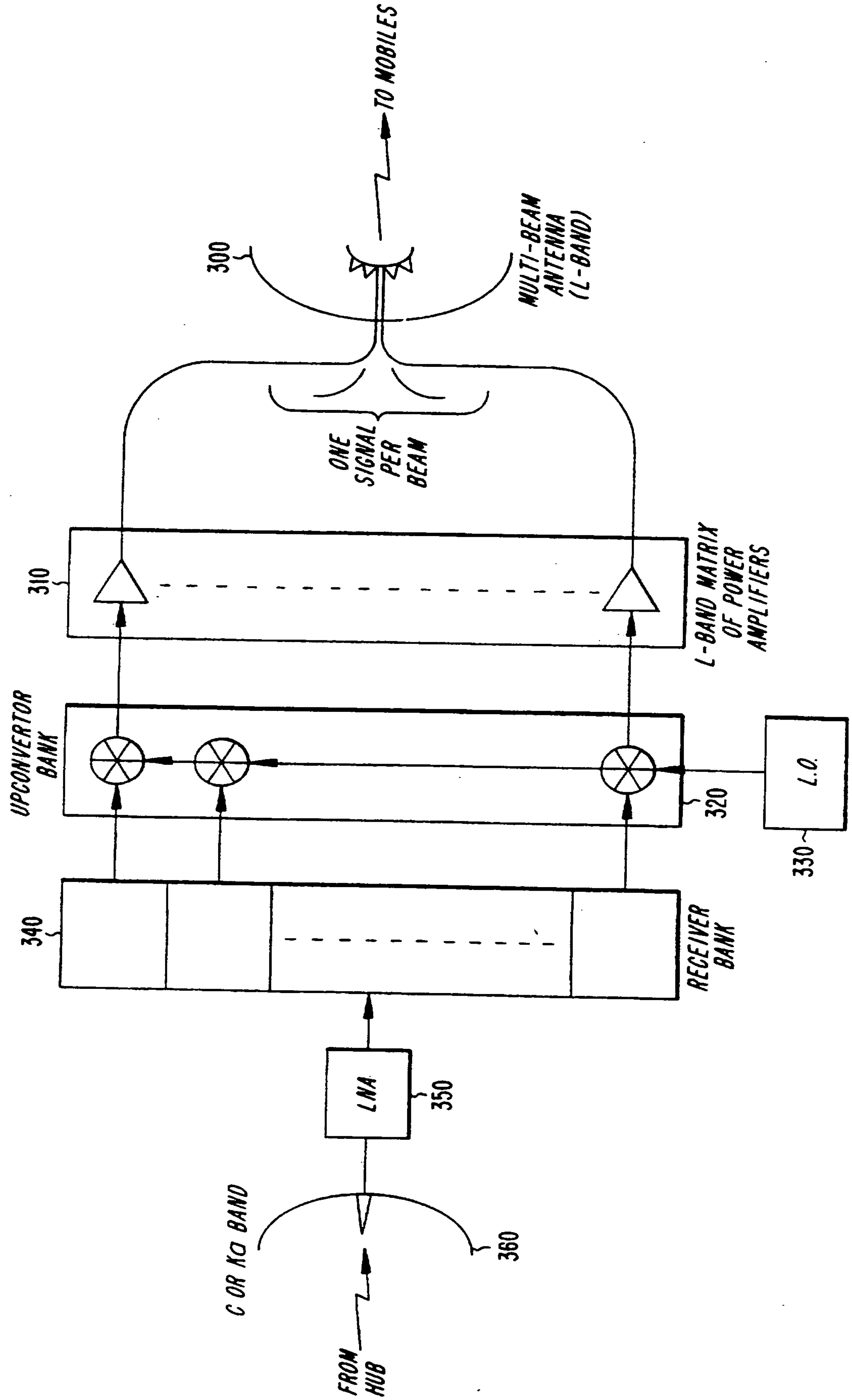

TO MOBILES
300
MULTI-BEAM ANTENNA (L-BAND)
ONE SIGNAL PER BEAM
310
L-BAND MATRIX OF POWER AMPLIFIERS
UPCONVERTOR BANK
320
L.O.
330
340
RECEIVER BANK
LNA
350
C OR Ka BAND
360
FROM HUB

Fig. 11

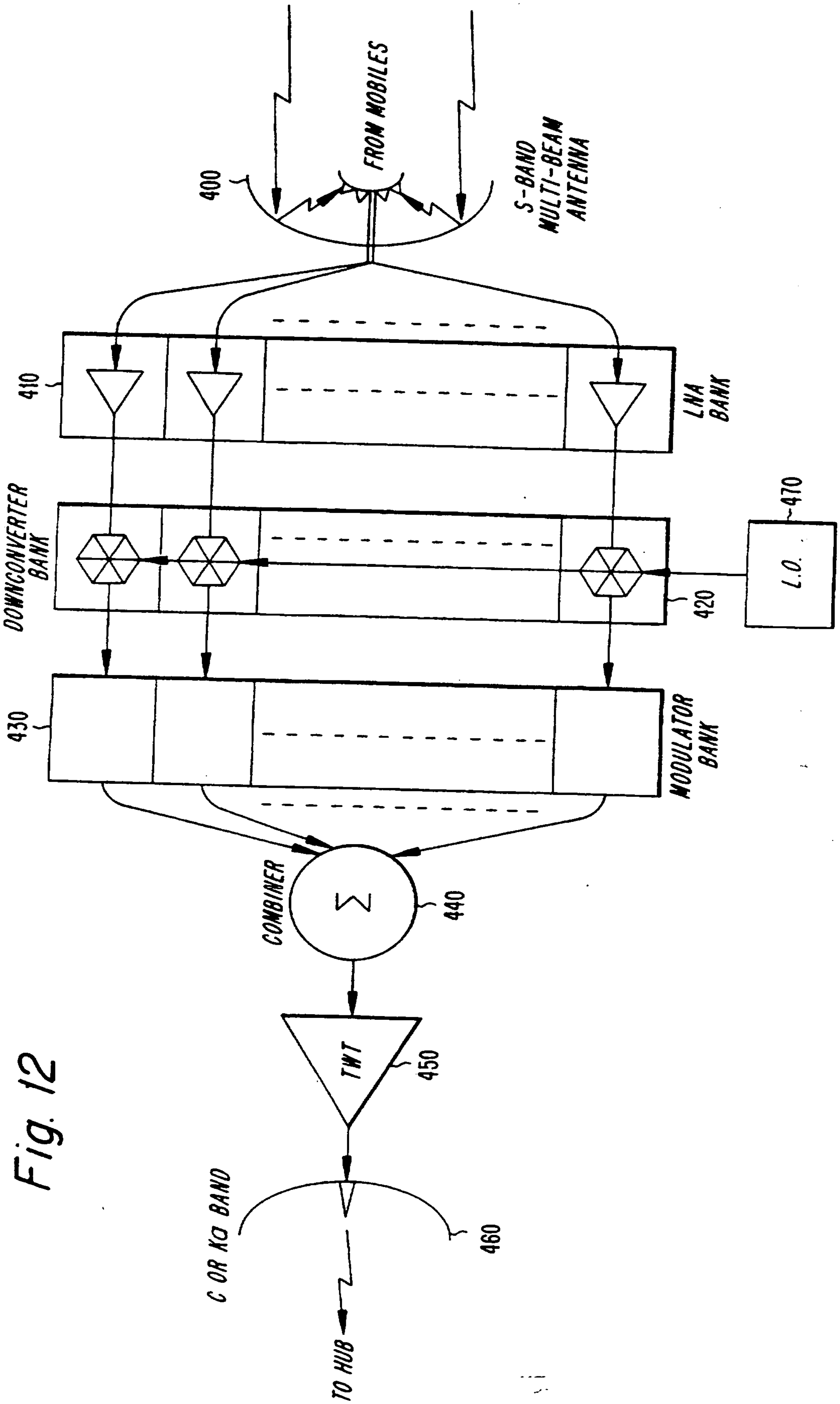

FROM MOBILES
400
S-BAND
MULTI-BEAM
ANTENNA
410
LNA
BANK
DOWNCONVERTER
BANK
470
L.O.
420
430
MODULATOR
BANK
COMBINER
440
TWT
450
C OR Ka BAND
460
TO HUB

Fig. 12

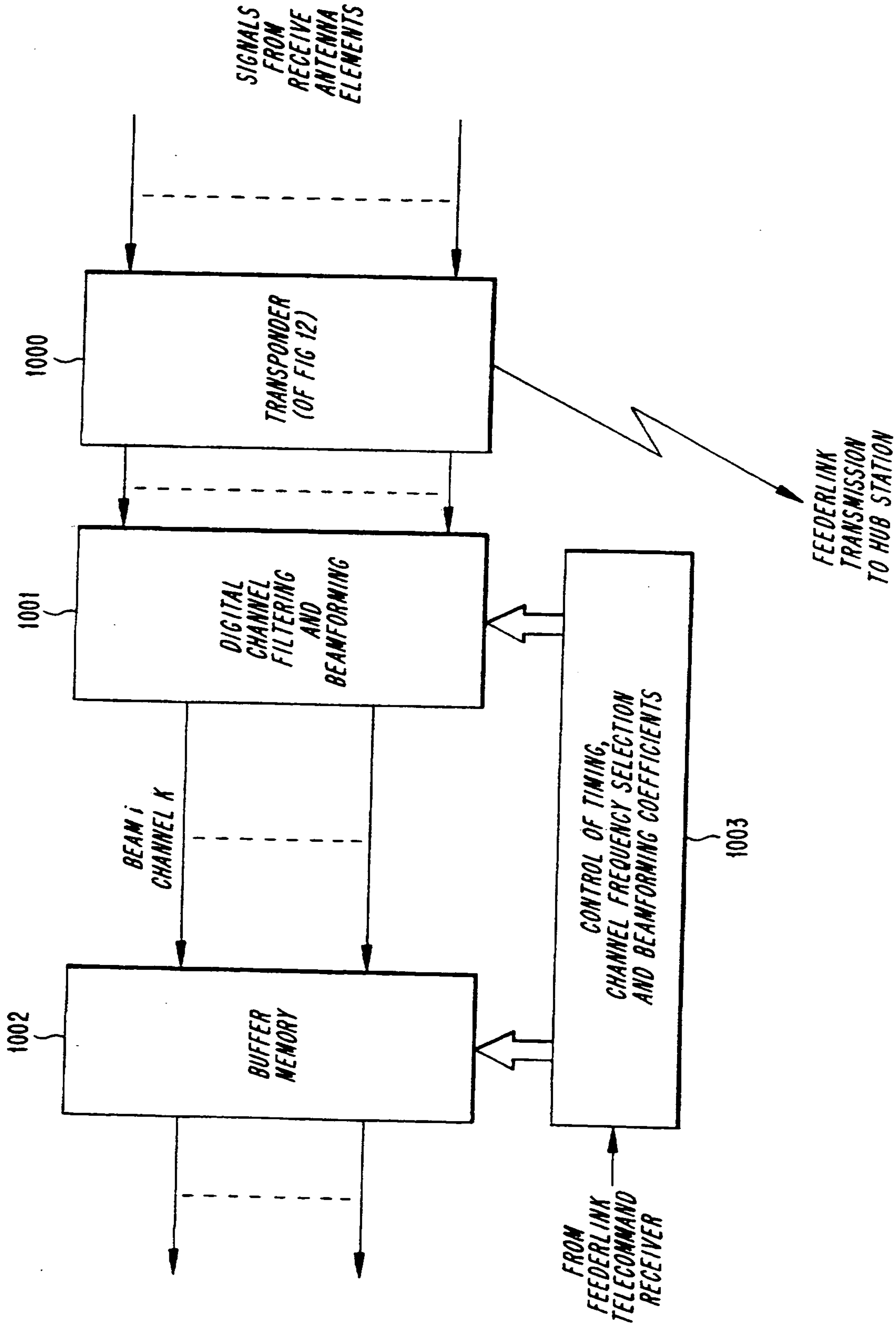

SIGNALS FROM RECEIVE ANTENNA ELEMENTS
1000
TRANSPONDER (OF FIG 12)
FEEDERLINK TRANSMISSION TO HUB STATION
1001
DIGITAL CHANNEL FILTERING AND BEAMFORMING
BEAM i CHANNEL K
1002
BUFFER MEMORY
CONTROL OF TIMING, CHANNEL FREQUENCY SELECTION AND BEAMFORMING COEFFICIENTS
1003
FROM FEEDERLINK TELECOMMAND RECEIVER

Fig. 13a

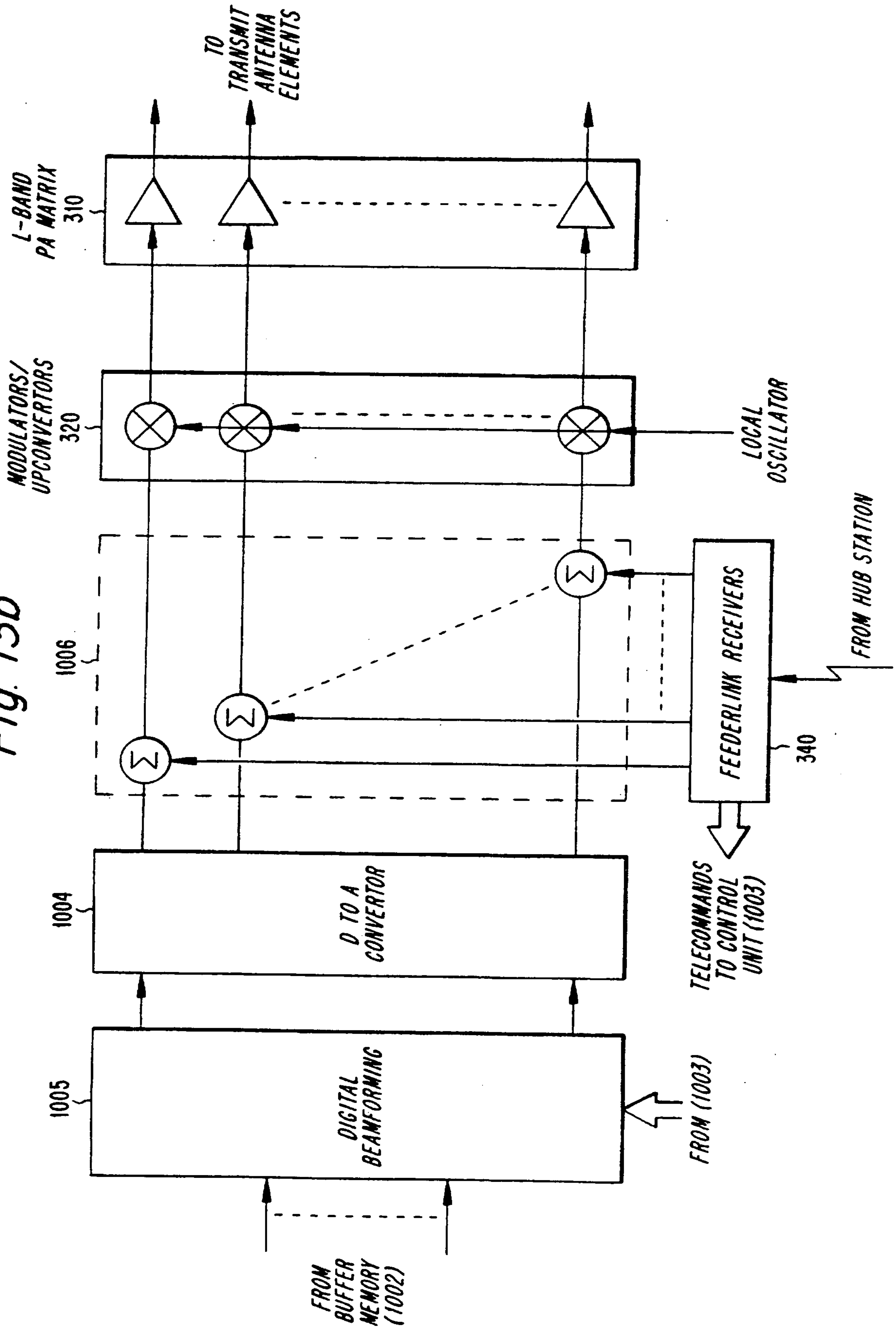

TO TRANSMIT ANTENNA ELEMENTS
L-BAND PA MATRIX
310
MODULATORS/ UPCONVERTORS
320
LOCAL OSCILLATOR
1006
FROM HUB STATION
FEEDERLINK RECEIVERS
340
TELECOMMANDS TO CONTROL UNIT (1003)
1004
D TO A CONVERTOR
1005
DIGITAL BEAMFORMING
FROM (1003)
FROM BUFFER MEMORY (1002)

Fig. 13b

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(71) Applicant: ERICSSON INC. [US/US]; 7001 Development Drive, P.O. Box 13969, Research Triangle Park, NC 27709 (US).

(72) Inventor: DENT, Paul, W.; Stehags Prästgård, S-240 36 Stehags (SE).

(74) Agents: GRUDZIECKI, Ronald, L. et al.; Burns, Doane, Swecker & Mathis, L.L.P., P.O. Box 1404, Alexandria, VA 22313-1404 (US).

(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

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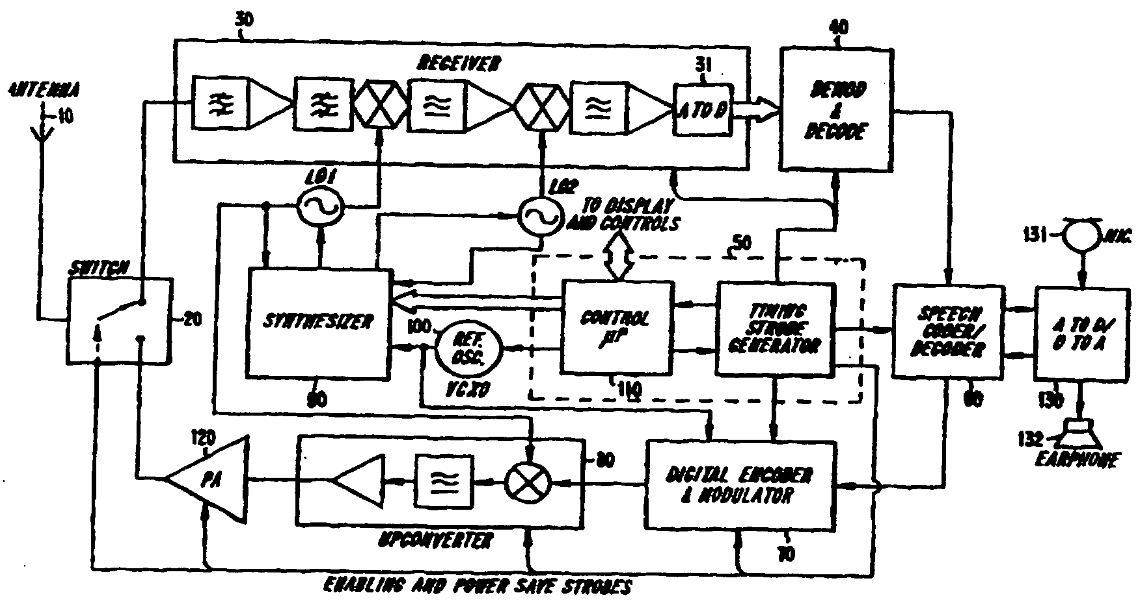
(54) Title: TIME COMPRESSING TRANSPONDER




**(57) Abstract**

A method for supporting calls between two mobile stations within a satellite communication system is disclosed. First, when signals transmitted by a first mobile station using a narrowband transmission format are received at a satellite relay station, the received signals are sampled and digitized. The sampled and digitized signals are then stored in a buffer at a first rate. The stored data is then read out of the buffer at a faster rate than the first rate and modulated onto a downlink frequency to create a wideband transmission format. The modulated signals are then transmitted to the second mobile station.

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PCT/US 96/20161

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B7/204

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| Y | WO 95 19078 A (ERICSSON GE MOBILE COMMUNICAT) 13 July 1995<br>cited in the application<br>see page 11, line 14 - page 12, line 9<br>--- | 1-3,7,11 |
| Y | US 4 145 573 A (ARNOLD) 20 March 1979<br>see column 2, line 20 - column 5, line 5<br>--- | 1-3,7,11 |
| A | US 5 199 031 A (DAHLIN JAN E AANGSTROEM S) 30 March 1993<br>see column 4, line 8 - line 35<br>---<br>-/-- | 4-6,8-10 |

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| A | WO 92 19050 A (MOTOROLA INC) 29 October 1992<br>see page 4, line 20 - page 5, line 7 | 1-3 |
| A | GB 2 221 368 A (NIPPON ELECTRIC CO) 31 January 1990<br>see page 1, line 18 - page 2, line 11 | 1-3 |
| A | EP 0 507 384 A (PHILIPS ELECTRONICS UK LTD ;PHILIPS NV (NL)) 7 October 1992<br>see page 1, line 3 - line 43 | 1-3 |

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| | | CA 2107660 A | 16-10-92 |
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